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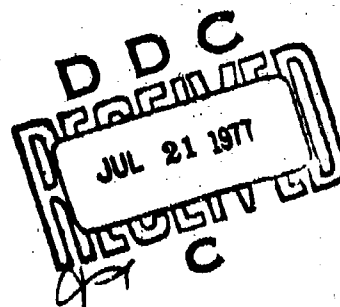
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REPORT ON ATMOSPHERIC ENVIRONMENT INTERACTIONS  
WITH FREE AND TETHERED BALLOONS

ROBERT L. VESPRIMI  
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April 1977

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→ THESE TECHNIQUES (INCLUDING FLOWCHART AND DOCUMENTATION).

III TETHERED BALLOON EXPERIMENT: ANALYSIS AND RECOMMENDATIONS

IV BALLOON FLIGHT SIMULATIONS USING EGLIN APB, HOLLOMAN,  
AND WHITE SANDS WIND DATA.



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## INTRODUCTION

This report contains information in four areas:

- (1) ✓ Air-Launched Balloon System (ALBS): Programs, their description, Flowcharts, and Documentations;
- (2) ✓ Balloon Tracking Using VOR: Description and Logic of Mathematical Development, and a Program Employing These Techniques (Including Flowchart and Documentation);
- (3) ✓ Tethered Balloon Experiment: Analysis and Recommendations; and
- (4) ✓ Balloon Flight Simulations Using EUGEN AFB, HOLLOMAN, and WHITE SANDS Wind Data.

## I. ALBS Program Documentation

### Introduction

This write-up describes programs pertaining to the Air-Launched Balloon System (ALBS), which were originally written for a desk-top calculator (Wang Model 452-1), by Andrew Carten (AFGL), ALBS development program manager.<sup>1</sup> These programs have now been put in Fortran so that they may be run on the the CDC 6600, and this section provides all information necessary to run these programs. For each program are provided a description, listing, flow chart, sample deck set-up, sample output, and definitions of all nomenclature, i.e., the variable names, used in the program. As much as possible, the original program names, subroutine names, and variable names have been retained. The underlying mathematics and logic, unless different, are not described in any depth here. For a more comprehensive treatment the reader should consult the Carten report.<sup>1</sup>

The first program, called CHUTE, treats the ALBS system as the drogue and main parachutes are being deployed. The second program, called P14B, treats the system as the balloon is being inflated.

Note that within the descriptions, flow charts, etc. variable names are often referred to without explanation. The reader is referred to the appropriate section on 'Nomenclature'.

## Program CHUTE

This program computes theoretical-performance data (velocity, drag, dynamic pressure, etc.) for the ALBS system starting from the point when either the drogue parachute or the main parachute is beginning to open until it is fully opened ( $0 \leq t \leq TF$ ). The computations are based on an initially chosen opening time ( $TF = TFI$ ). The volume of the filled parachute is then computed. If the calculated volume, using the initial opening time, is sufficiently close (less than 200 cu ft) to the theoretical volume, the program goes on. If not, a new opening time is chosen, and the first calculation is repeated.

When an acceptable opening time has been found, the behavior of the system at  $t > TF$  is computed. The calculations are continued until the velocity of the system is 'sufficiently close' to the equilibrium velocity ( $VEHI$ ). The criterion for 'sufficiently close' is satisfied when the change in the dynamic pressure ( $Q$ ) becomes 'very small'. The system data at this point become the starting data for another program not described here.

The program then reverts back to the time period during which the parachute was in the process of opening ( $0 \leq t \leq TF$ ), and it calculates deceleration and opening shock forces.

Data input to the program is by means of a READ statement. Each time the READ statement is executed, i.e., each line (or card) of input data is read a new set of calculations is done. Any number of sets of calculations may be done at one time. In this way, parametric studies of any of the parameters in the READ statement can be done easily. The data must be 'unformatted', i.e., the variables must be separated by commas.

Each time a new opening time (TF) is tried, subroutine P4U is called with its first argument equal to 0, and one page of output is written. When an appropriate opening time is found, P4U is called again, but this time with its first argument equal to 1, and calculations are made for  $t > TF$ . This output is printed on the same page. Subroutine P10 is then called to calculate the acceleration and opening shock forces, and this output is written on a new page.

The output of the program is written on tape 1 and tape 2. Tape 1 contains the output of main interest, while on tape 2 is written supplementary information as well as results of calculations used for checking purposes.

(Note that in the program there are statements with 'CHECK' written in the first 5 columns. Because there is a 'C' in column 1, they are treated by the computer as comment cards. In order to use these statements the 'CHECK' must be deleted.)

```

1      PROGRAM CHUTE (TAPE1,TAPE2,INPUT,TAPE3=INPUT)      000100
      CC                                                    000110
      CC ALJS PARACHUTE DEPLOYMENT CALCULATIONS           000120
      CC WRITTEN FOR A GARTEN, AFGL                        000130
      CC BY ROBERT VESPRINI, EMMAUEL COLLEGE, 2/77        000140
      CC                                                    000150
      COMMON /VEL/ V(21), DVL(11)                        000160
      COMMON /CONST/ PI,G0,00,TF,CD,M                    000170
      DATA PI,G0/3.14159, 32.2/                          000180
      10                                                    000190
      CC READ DATA                                         000200
      READ (5,*) KMAX, H0, M, TFI, J, CD, D0, CP, VO      000210
      IF (EOF(5)).NE.0) STOP                                000220
      15                                                    000230
      CC WRITE HEADINGS FOR TAPE2                          000240
      WRITE (2,20) UATE(TODAY)                             000250
      WRITE (2,22) M,D0,CD,CP                              000260
      WRITE (2,24)                                           000270
      20                                                    000280
      CC INITIALIZE REQUIRED VARIABLES                      000290
      F = 1. 8 TF = TFI                                     000300
      DTF = .1                                              000310
      SO = (PI*D0**2)/4.                                     000320
      VLMAX = (2./(3.*PI**2))*D0**3                         000330
      25                                                    000340
      CC START CALCULATIONS, ONE VALUE OF TF FOR EACH KOUNT 000350
      DO 100 KOUNT = 1,KMAX                                 000360
      CALL P4J (0,H0,M,VO,VF1,B)                           000370
      VEMI = SQRT(M/(1.001189*SIGMA(H0)*CD*SO))             000380
      31                                                    000390
      CC SUBROUTINES P9 AND P7U IN A. GARTEN'S PROGRAMS     000400
      VL = 0.                                               000410
      D1 = D0**2*TF/PI                                     000420
      DO 100 J = 1,11                                       000430
      T = FLOAT(J-1)/10.                                    000440
      35 DVL(J) = -G1*V(J)*((1.-T)*T**(4./3.) - 2.*CP*T*(1.-T)) 000450
      VL = VL + .1*DVL(J)                                  000460
      41 CONTINUE                                           000470
      WRITE (2,26) V                                         000480
      WRITE (2,26) DVL                                       000490
      43                                                    000500
      CC IS TF ACCEPTABLE? IF IT IS, GO TO 200.           000510
      DIFFVL = ABS(VLMAX - VL)                              000520
      IF (DIFFVL.LE.200.) GO TO 200                         000530
      F = (VLMAX - VL)/DIFFVL                               000540
      WRITE (1,10) KOUNT,TF,VLMAX,VL,DIFFVL                000550
      WRITE (2,10) KOUNT,TF,VLMAX,VL,DIFFVL                000560
      IF (DIFFVL.LE.1000.) DTF = .02                       000570
      TF = TF + F*DTF                                       000580
      51 CONTINUE                                           000590
      20 CONTINUE                                           000600
      53                                                    000610
      CC MAKE CALCULATIONS FOR TIME,GT,TF                 000620
      CALL P4U (1,M,MP,VF1,VF3)                             000630
      55                                                    000640
      WRITE (1,11) TF, VEMI, VLMAX, VL                    000650
      WRITE (2,10) KOUNT,TF,VLMAX,VL,DIFFVL                000660
      60                                                    000670
      CC MAKE CALC OF ACC AND FORCES, WHILE CHUTE IS BEING 000680
      DEPLOYED. CALL P10 (H0)                               000690
      62                                                    000700
      10 FORMAT (1H0,15,F10.2)                             000710
      11 FORMAT (1H0,///,11X,'OPENING TIME = ',F8.2,8X,'VEMI = ',F7.2 000720
      1,/,11X,'VOLMAX = ',F10.2,10X,'CALC VOLUME = ',F10.2) 000730
      65 20 FORMAT (1H1,'ALBS -- SUPPLEMENTARY INFORMATION',10X,A10) 000740
      22 FORMAT (1H0,10X,'INPUT VARIABLES NOT LISTED ELSEWHERE',// 000750
      1,'* SYSTEM HEIGHT = ',F9.1,15X,'* DIAM OF CHUTE = ',F8.3,// 000760
      2,'* COEFF OF DRAG = ',F8.3,15X,'* C OF POROSITY = ',F8.3,// 000770
      24 FORMAT (1H0,10X,'OTHER CALCULATED VARIABLES')     000780
      70 26 FORMAT (1H0,11F10.2)                             000790
      STOP                                                  000800
      END                                                    000810

```

SUBROUTINE P10

74/74 OPT=1

FTN 4.8+414

05/12/77 13.12.36

```

1      SUBROUTINE P10 (H)
      COMMON /VEL/ V(21), DVL(11)
      COMMON /CONST/ PI,G0,00,TF,CD,H
      DIMENSION CVOT(11)
5      CC      INITIALIZE REQUIRED VARIABLES
      COSM = CO*(PI/4.)*00**2
      A = (H*100000.)/(SIGMA(H)*G0*00**3)
      B = 120.*COSM/00**3
      C = A*G0
10     CC      WRITE HEADINGS ON TAPE1
      WRITE (1,1) DATE(TDAY)
15     CC      START CALCULATIONS, INTERVALS OF TF/10.
      DO 100 I = 1,11
      T = FLOAT(I-1)/10.
      DVOT(I) = (22.5*V(I) - 3*TF*T*V(I)**2 + C*TF)/(A + 22.5*T)
      F = -(H/(G0*TF))*DVOT(I)
      F0 = F + H
      S = F0/H
20     CC      WRITE ONE LINE OF OUTPUT
      WRITE (1,10) T, DVL(I), DVOT(I), F, F0, S
25     CC      CONTINUE
      CC      WRITE ADDITIONAL INFORMATION
      WRITE (1,20) A, B, C, COSM
30     1      FORMAT (1H1,10X,'PROGRAM P9',13X,'PROGRAM P10',20X,A10,////
      1,10X,'T/TF      DVL (CUFT) DV/DT (FPS/S)',10X,'F(LB)',9X,
      2,'F0(LB)',7X,'F0/H (G)',1)
      10     FORMAT (1H0,10X,F8.1,4F10.2,F14.3)
      20     FORMAT (1H0,10X,'A = ',F12.3,5X,'B = ',F14.5,5X,'C = ',F12.3,//
      1,5X,'COSM = ',F12.2)
35     RETURN
      END

```

FUNCTION SIGMA

74/74 OPT=1

FTN 4.8+414

05/12/77 13.12.36

```

1      FUNCTION SIGMA (H)
      DIMENSION SIG(25)
      C      THIS FUNCTION INTERPOLATES BETWEEN VALUES OF THE DENSITY RATIO,
      C      GIVEN BY SIG IN INTERVALS OF 1000 FT.
5      DATA SIG/.97107,.94278,.91513,.88811,.86170,.83590
      1,.81070,.78609,.76206,.73859,.71568,.69333,.67151
      2,.65022,.62946,.61921,.60946,.59021,.57144,.55315
      3,.53534,.51798,.50106,.48462,.46859/
      J = H/1000.
      XJJ = H - 1000.*FLOAT(J)
      SIGMA = SIG(J) + (SIG(J+1) - SIG(J))*XJJ/1000.
      RETURN
      END

```

```

1      SUBROUTINE P4U (IFLAG,H0,MF,V0,VF,B)
CC      IFLAG = 0 -- CHUTE IS BEING DEPLOYED
CC      IFLAG = 1 -- CHUTE HAS BEEN DEPLOYED
COMMON /CONST/ PI,G0,D0,TF,CD,M
5      COMMON /VEL/ V(21), CVL(11)

CC      INITIALIZE REQUIRED VARIABLES
      S0 = (FI*D0**2)/4.
      Z = .001189*SIGMA(H0)*V0**2

10     C      WRITE HEADINGS FOR TAPE1, IF NECESSARY.
      IF (IFLAG.EQ.1) GO TO 90
      WRITE (1,10) DATE(TODAY)
      WRITE (1,2) 9, Q, V0, H0

15     50    CONTINUE

      V(10*IFLAG+1) = VI = V1 = V0
      H = H0
      QI = C.
20     DT = TF/50.
      DVI = DVO = -G0*DT*(1. - Q*CD*S0*FLOAT(IFLAG)/M)
      IBB = 50*IFLAG + 1 & IFF = IBB + 49

CC      START CALCULATIONS, INTERVALS OF DT = TF/50.
25     DO 100 I = IBB,IFF
      T = FLOAT(I)/50.
      TIME = T*TF
      A = (S0-3)*AMIN1(T,1.) + 8
      DVPRE = 2.*DVI - DVO
30     VPRE = V1 + DVPRE
      VEAV = (V1 + VPRE)/2.
      DMPRE = VEAV*DT
      Q = .001189*SIGMA(H+DMPRE)*VPRE**2
      D = Q*CD*A
35     DVI = -G0*DT*(1. - D/M)
      VI = V1 + DVI
      DHI = .5*(VI + V1)*DT
      H = H + DHI
      V1 = VI
40     DVO = DVI
      DVI = DVI

CC      WRITE ONE LINE OF OUTPUT, EVERY FIFTH CALCULATION
45     II = MOD(I,5)
      IF (II.NE.0) GO TO 90
      IJ = I/5 + 1
      V(IJ) = VI
      WRITE (1,1)A,T,TIME,Q,DVI,VI,D,H

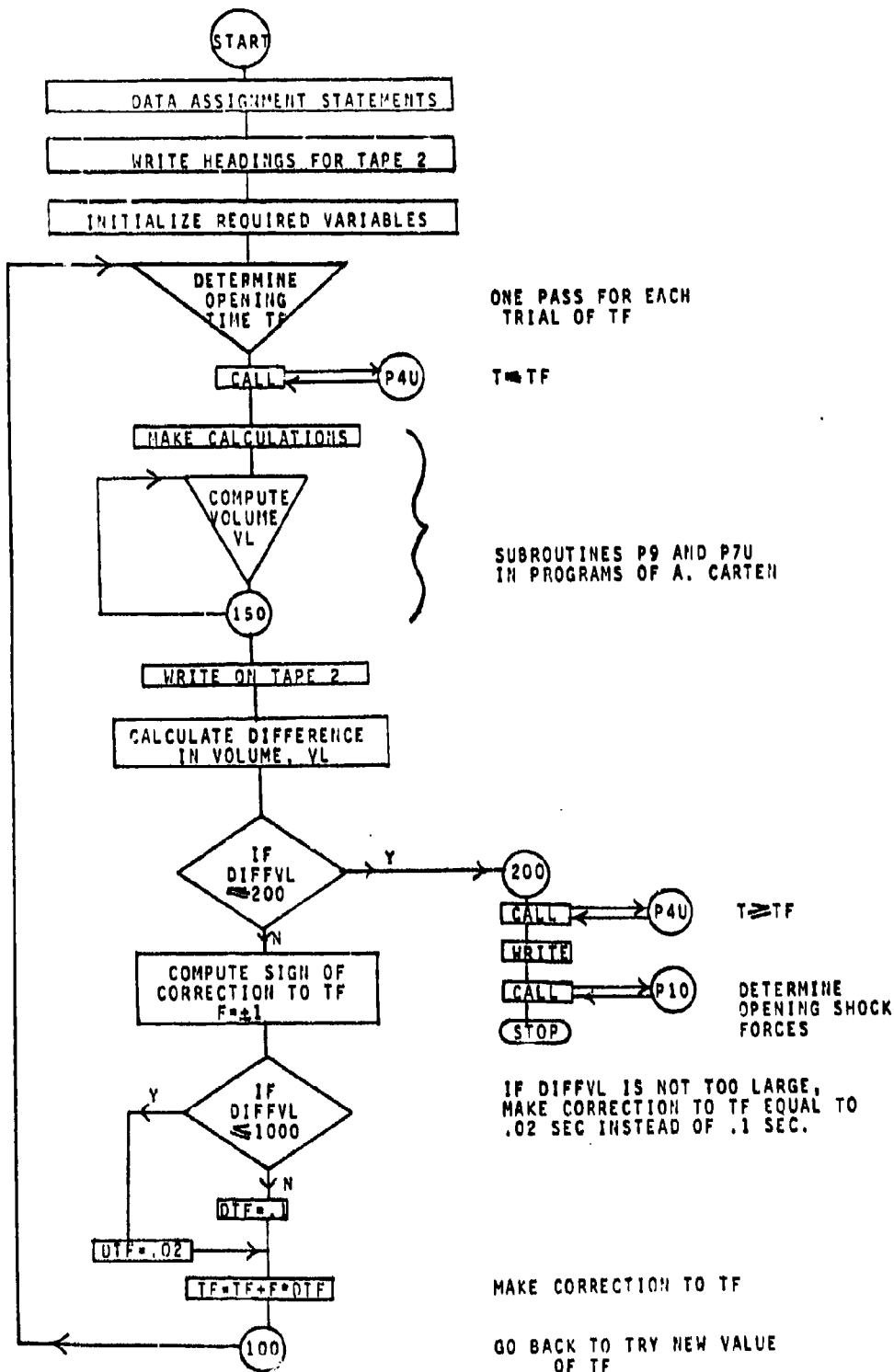
50     CC      FOR IFLAG = 1, CALC STOPS WHEN DIFF IN Q IS SMALL
      IF (IFLAG.EQ.0) GO TO 90
      DIFFQ = ABS(Q - QI)
      IF (DIFFQ.LE..001) RETURN
      QI = Q
55     90    CONTINUE

      CHECK IF (IFLAG.EQ.1) WRITE (2,1) A,T,TIME,Q,DVI,VI,D,H
      CHECK WRITE (2,1) A, T, TIME, Q, DVI, VI, D, H
      100   CONTINUE

60     CC      HF AND VF ARE OUTPUT OF P4U SENT BACK TO ALBS
      HF = H & VF = VI
      WRITE (2,2) 8,Q,VF,HF
      FORMAT (1H0,10X,F11.2,F8.1,F9.2,2F11.4,3F11.2)
65     2      FORMAT (1H,10X,F11.2,17X,F11.4,11X,2(F11.2,11X))
      10     FORMAT (1H1,10X,*PROGRAM P4U *,A10,////
      1,12X,*AREA(SQFT) T/TF T(SEC) Q(PSF) DV(FPS) V(FPS)
      2 C(LB) H(FT)*,/)
      RETURN
70     END

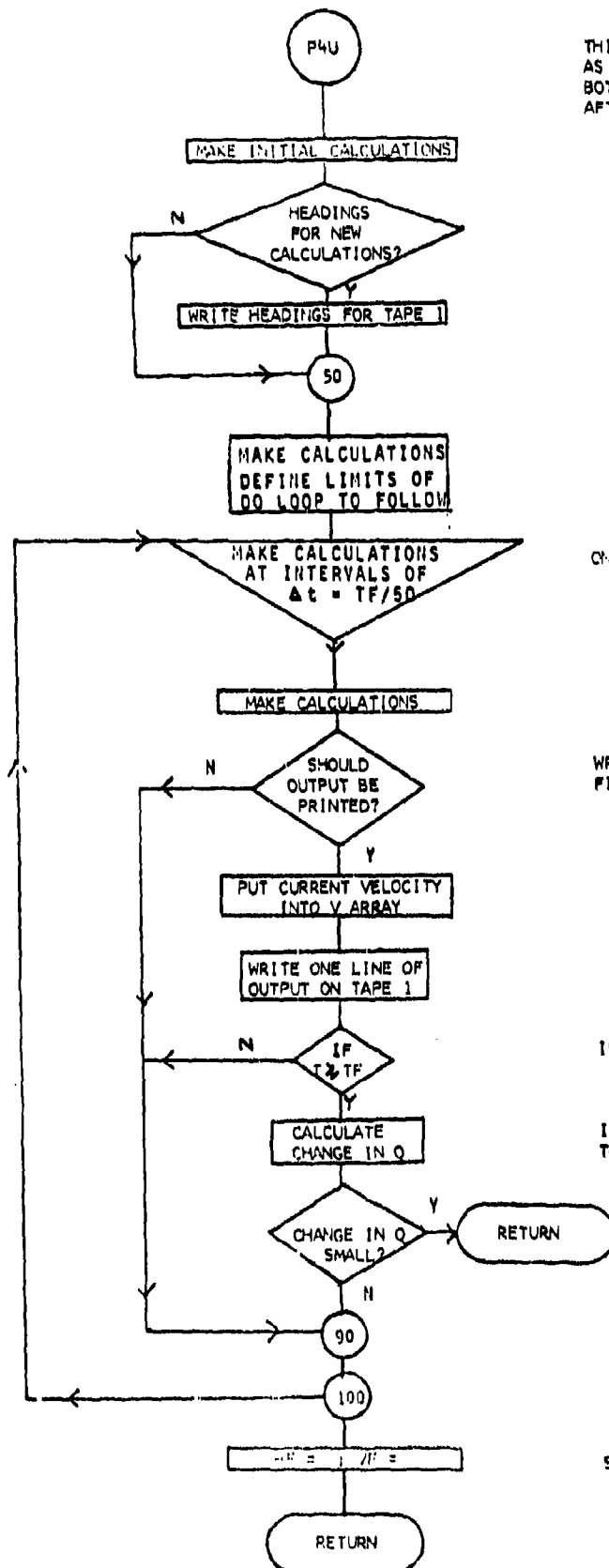
```

# PROGRAM CHUTE



# SUBROUTINE P4U

THIS SUBROUTINE MAKES CALCULATIONS AS THE CHUTE IS DESCENDING, BOTH WHILE IT IS OPENING AND AFTER IT HAS OPENED.



ONE PASS FOR EACH TIME.

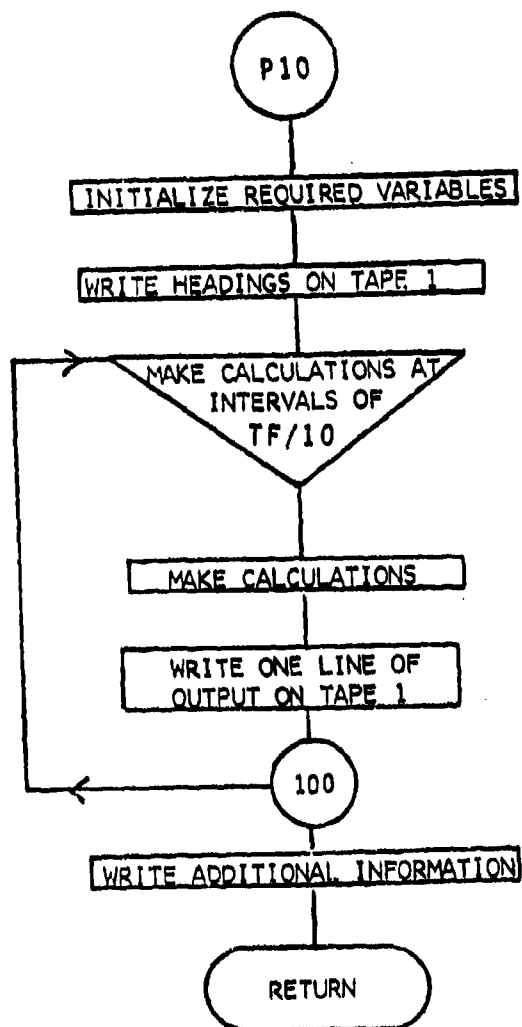
WRITE ONE LINE OF OUTPUT EVERY FIFTH CALCULATION.

IS PARACHUTE FULLY OPENED?

IS VELOCITY SUFFICIENTLY CLOSE TO EQUILIBRIUM VELOCITY (V<sub>EH</sub>)?

SET FINAL HEIGHT AND VELOCITY.

SUBROUTINE P10



THIS SUBROUTINE COMPUTES OPENING SHOCK FORCES.

ONE PASS FOR EACH TIME INTERVAL.

10.23771, 1430, 3.5, 962.11, .755, 72.945, .048, -47.62

[illegible]

```

COPY, TAPE2, OUTPUT.
COPY, TAPE1, OUTPUT.
REWIND, TAPE1, TAPE2.
LEO.
LDCCT, PRECCT=ZERO.
FIN.
VEEPA.

```

1        1 1 1 1  
 2        2 2        2

[illegible]

PROGRAM P4U 35/12/77

AREA (SQFT)	T/TF	T (SEC)	Q (PSF)	DV (FPS)	V (FPS)	U (LB)	H (FT)
962.11			1.2623		-47.62		23771.00
1283.01	.1	.35	1.3765	-.1509	-49.65	1334.27	23753.90
1605.50	.2	.70	1.3365	.2996	-48.97	1620.04	23735.58
1927.20	.3	1.05	1.2157	.5342	-46.53	1768.89	23719.81
2243.90	.4	1.40	1.0684	.6053	-43.75	1814.04	23703.37
2570.59	.5	1.75	.9280	.5848	-40.75	1880.98	23683.13
2892.29	.6	2.10	.8873	.5248	-38.01	1762.94	23675.41
3213.99	.7	2.45	.7883	.4552	-35.60	1718.79	23662.54
3535.69	.8	2.80	.6284	.3899	-33.52	1677.35	23650.45
3857.38	.9	3.15	.5637	.3337	-31.74	1641.74	23639.04
4179.08	1.0	3.50	.5110	.2874	-30.22	1512.35	23628.20
1 3.50	26217.80	26451.65	233.84				

AREA (SQFT)	T/IF	T (SEC)	Q (PSF)	QV (FPS)	V (FPS)	D (LB)	H (FT)
982.11			1.2623		-47.62		23771.00
1283.61	.1	.35	1.3760	-.1509	-49.64	1333.73	23754.00
1605.50	.2	.70	1.3364	.2976	-46.97	1619.89	23736.78
1927.20	.3	1.04	1.2161	.5321	-46.70	1769.51	23720.10
2240.90	.4	1.39	1.0692	.6040	-43.77	1915.40	23704.35
2570.59	.5	1.74	.9283	.5842	-40.78	1802.79	23689.65
2892.29	.6	2.09	.8002	.5249	-38.03	1764.90	23675.94
3213.99	.7	2.44	.7091	.4556	-35.62	1720.70	23663.14
3535.69	.8	2.78	.6290	.3904	-33.54	1679.09	23651.11
3857.38	.9	3.13	.5642	.3342	-31.76	1643.27	23639.76
4179.08	1.0	3.48	.5114	.2879	-30.23	1613.69	23628.98
4179.08	1.1	3.83	.4805	.1348	-29.30	1516.01	23618.64
4179.08	1.2	4.10	.4663	.0648	-28.95	1471.37	23608.53
4173.08	1.3	4.52	.4595	.0314	-28.64	1450.61	23598.53
4174.08	1.4	4.87	.4564	.0155	-26.53	1439.90	23588.59
4173.08	1.5	5.22	.4548	.0079	-26.48	1435.07	23578.57
4179.38	1.6	5.57	.4541	.0043	-24.45	1432.76	23568.76

OPENING TIME = 3.48

VEHI = 28.53

VOLMAX = 26217.68

CALC VOLUME = 26310.60

PROGRAM P9

PROGRAM P10

05/12/77

T/TF	DVOL (CUFT)	QV/GT (FPS/S)	F(LB)	F8(LB)	F0/W (G)
0.0	-0.00	68.19	-870.26	553.74	.391
.1	9694.18	29.39	-375.05	1854.95	.738
.2	22572.17	.26	-3.38	1426.62	.998
.3	33143.30	-17.13	218.55	1640.55	1.153
.4	39675.81	-25.39	324.85	1754.85	1.227
.5	41929.29	-28.13	358.96	1788.96	1.251
.6	40212.03	-28.87	358.20	1788.20	1.250
.7	34918.18	-26.84	342.49	1772.49	1.240
.8	26323.58	-25.26	322.33	1752.33	1.225
.9	14647.51	-23.69	302.31	1732.31	1.211
1.0	-0.00	-22.26	284.11	1714.11	1.193
A =	24.428	B = .97349	C =	786.573	
COS0 =	3155.20				



## Nomenclature

### Program CHUTE

B	Cross-sectional area (b) of parachute at $t=0$
CD	Coefficient of drag, $C_D$
CP	Coefficient of porosity, $C_p$
C1	$(C1) = d_o^2 t_f / \pi$
DIFFVL	Absolute difference between the calculated and theoretical parachute volume
DTF	Correction to $t_f$ to get DIFFVL below an arbitrary limit
DVL	Rate of change ( $dV/dT$ ) of volume with $T = t/t_f$
DO	Parachute diameter, $d_o$
F	Number used to decide whether $t_f$ should be increased or decreased to produce an acceptable parachute volume.
GO	Acceleration of gravity ( $g_o = 32.2 \text{ft/sec}^2$ )
H	Final height returned from subroutine P4U
HF	Final height after chute has achieved equilibrium velocity
HO	Initial height, $H_i$
J	Index used to increment successive iteration
KMAX	Maximum number of different opening times ( $t_f$ ) that will be tried for a given run. This is an additional safeguard against the program going into infinite loop.

KOUNT	Index used to count the number of different opening times ( $t_f$ ) that have been tried.
PI	$\pi$
SIG	Array defining $\sigma$ at 1000-ft intervals, where $SIG(I) = \sigma(h=1000 \cdot I)$ , up to 25000 ft.
S0	Cross-sectional area ( $S_0$ ) of parachute when fully opened ( $t=t_f$ )
T	Fraction of opening time, $T = t/t_f$
TF	Opening time, $t_f$
TFI	Initial value of opening time, read into the program
TODAY	Dummy variable used to print date
V	Array containing values of velocity ( $v$ ), where $V(1) = v(T=.1)$ , $V(2)=v(T=.2)$ , etc.
VEHI	Equilibrium velocity ( $V_{e(Hi)}$ ) of parachute system
VF	Final velocity, $VF=VEHI$
VFI	Velocity after parachute is fully opened ( $t=t_f$ )
VL	Parachute volume calculated using opening time $t=t_f$
VLMAX	Theoretical parachute volume
VO	Initial velocity of parachute system (at $t=0$ )
W	Weight of parachute system, $W_s$

## Nomenclature

### Subroutine P4U

A	Cross-sectional area of parachute at a given time $t$
B	Same as in CHUTE
CD	Same as in CHUTE
D	Drag of parachute, $D$
DHI	Change in height in time $DT = t_f/50$
DHPRE	Initial calculation of change in height
DIFFQ	Change in $q$ in time $t = .1t_f$ . This is used only after the chute is fully opened ( $IFLAG = 1$ ) to determine if the velocity ( $V$ ) is close enough to the equilibrium velocity ( $VEHI$ )
DT	Time increment/iteration; $DT = t_f/50$
DVI	Change in velocity ( $V$ ) in time $DT$
DVL	Same as in CHUTE
DVPRE	Initial calculation of velocity change in time $DT$
DVO, DVI	Used in determining DVPRE. They are the two previous DVI's
DO, GO	Same as in CHUTE
H	Height
HF	Final height when P4U returns control to CHUTE
H0	Initial height when P4U starts
I	Index used to increment successive iterations

IBB, IFF	Beginning and final values of index I
IFLAG	Index used to tell P4U whether the parachute is in the process of opening (IFLAG = 0, $0 \leq t \leq t_f$ ) or is fully opened (IFLAG = 1, $t \geq t_f$ )
II	Index to determine whether a particular iteration should be printed. (Only 1 out of 5 is printed)
IJ	Index used to place a velocity value (VI) into the array V; this index corresponds to a time such that $V(IJ)=v(T)$ , $IJ=10*T+1$
PI	Same as in CHUTE
Q	Dynamic pressure, $q = \frac{1}{2} \rho v^2$
QI	Previous value of Q; used to calculate DIFFQ
S0, T, TF	Same as in CHUTE
TIME	Real time t(sec)
TODAY,V	Same as in CHUTE
VEAV	Average velocity over the interval DT
VF	Final velocity when P4U returns control to CHUTE
VI	New velocity at end of time increment DT
VPRE	Preliminary value of new velocity at end of time increment DT
VO	Initial velocity when P4U starts
VI	Used to store the previous velocity (VI)
W	Same as in CHUTE

# Nomenclature

## Subroutine P10

A,B,C	Coefficients used to calculate DVDT
CD	Same as in CHUTE
CDSOM	$(C_D S_O)_m = C_D S_O$
DVDT	Acceleration of parachute system (ft/sec <sup>2</sup> )
DVL, DO	Same as in CHUTE
F	Force produced by the drag of the parachute (lbs)
FO	Sum of the drag of the parachute and the force of gravity
G	Acceleration in g's corresponding to FO
H	Height at which $\sigma$ is to be calculated This value $\sigma(H)$ is held constant throughout the subroutine
I	Index used to specify the time ( $T=.1*I$ )
PI,T,TF,TØDAY,V,W	Same as in CHUTE

# Function SIGMA

H	Height at which SIGMA is to be calculated
J	Index used to determine 1000-ft interval
SIG	Same as in CHUTE
SIGHA	Value of $\sigma(H)$ calculated and returned to calling program or subroutine
XJJ	Variable which is used to interpolate $\sigma$ between $h=1000J$ and $h=1000(J+1)$

#### Program P14B

This program treats the ALBS system starting from the point when the balloon has been completely extracted, and the helium has begun to enter the balloon. Calculations are done every 200 ft, as the system descends through the atmosphere, and one line of output is printed for each height. The effect of the system weight, the drags of the drogue and main parachutes, the lift produced by the increasing volume of helium in the balloon, and the change in temperature and pressure of the atmosphere are all taken into account by the program.

Data is introduced to the program thru a READ statement. Each time a card of data is read, another set of calculations is done. Any number of sets of calculations may be done during the execution of the program. In this way, parametric studies of any of the parameters in the READ statement can be done easily. The data must be 'unformatted', i. e., the variables must be separated by commas.

The output of the program is written on tapes 1 and 2 (See Figures 1-4). After the headings are written, one line of output is written for each height (200-ft intervals). Since the values of so many variables are written, the width of one page of computer paper is not enough to write

them all across the page in one line. Hence, for each height, some of the variables are written on tape 1 (Figures 1 and 3) and the rest on tape 2 (Figures 2 and 4). After completion of the job, the pages are separated and each set of calculations is taped together so that the data for a given height can be read across the page in one line.

Each time another READ statement is executed, another set of calculations is done. For each new set of calculations, the headings are reprinted at the tops of new pages on tapes 1 and 2.

The Fortran version, explained here, also contains two new features not found in the original version written for the desk-top calculator. The first takes into account the adiabatic heating of the gas in the balloon as the system descends into a denser and denser atmosphere. The second provides an interpolation to determine the exact height at which the helium is exhausted (instead of the height of the nearest 200-ft interval) and the values of the other parameters at that height. These features are explained in detail below.

```

1      PROGRAM P143 (TAPE1,TAPE2,INPUT,TAPES=INPUT)      000100
      CC      ALBS BALLOON INFLATION CALCULATIONS      000110
      CC      WRITTEN FOR A. CARTEN, AFGL      000120
      CC      BY ROBERT VESPRINI, EMMAUEL COLLEGE, 2/77      000130
      CC      DIMENSION PRESS(25), SIG(25)      000140
      DATA PRESS/.9643,.9298,.8962,.8636,.8320,.8014,.7717,.7426,      000150
1      1 .7149,.6878,.6616,.6361,.6115,.5874,.5646,.5422,.5206,      000160
10     2 .4997,.4749,.4509,.4277,.4051,.3830,.3716/      000170
      DATA SIG/.97107,.94278,.91813,.88811,.86170,.83890      000180
1      1,.81070,.78609,.76206,.73859,.71568,.69333,.67151      000190
      2,.65022,.62946,.60921,.58946,.57021,.55144,.53316      000200
17     3,.51534,.49798,.48108,.46462,.44859/      000210
      DATA PI,C1,DM /3.14159,3.8413,-200./      000220
      CC      READ DATA      000230
19     90 READ (1,*) HI, WSREF, TME, TR, TREF, VO, DT, TLREL, WD, DAD, DAM      000240
      IF (EOF(5)).NE.0) STOP      000250
20     CC      INITIALIZE REQUIRED VARIABLES      000260
      TMME = 102.44      000270
      DTEMP = .8 S YEMP = TME      000280
      IFLAG = 0 S F = 1.      000290
      ITOP = IFIX(HI/200.) - 1      000300
25     IF (ITOP.GT.124) ITOP = 124      000310
      I = ITOP + 1      000320
      J = I/5      000330
      JJ = I - 5*J      000340
      SIGMA = SIG(J) + (SIG(J+1)-SIG(J))*FLOAT(JJ)/5.      000350
30     P = PRESS(J) + (PRESS(J+1)-PRESS(J))*FLOAT(JJ)/5.      000360
      VOL = TM = T = 0.      000370
      DAS = DAD + DAM      000380
      CC      WRITE HEADINGS AND DATA AT INITIAL HEIGHT      000390
35     90 WRITE (1,10) DATE(TODAY)      000400
      WRITE (1,11) TME,TREF,TR,DT      000410
      WRITE (2,12) DAM, DAD, WD, TLREL      000420
      WRITE (1,1)      000430
      WRITE (2,2)      000440
40     WRITE (1,13) HI, SIGMA, P, VO      000450
      WRITE (2,14) HI, WSREF, DAS      000460
      CC      START CALCULATIONS, 200-FT INTERVALS      000470
45     90 1000 II = 1,ITOP      000480
      I = ITOP - II + 1      000490
      J = I/5      000500
      DM = DT*TR      000510
      TMH = TM + DM      000520
50     CC      HAS HELIUM BEEN EXHAUSTED? IF NOT, GO TO 80.      000530
      IF (TMH.LT.TMME) GO TO 80      000540
      IFLAG = 1      000550
      F = (TMME-TM)/DM      000560
      TM = TMME      000570
55     90 20 TO 90      000580
      90 TM = TMH      000590
      90 CONTINUE      000600

```

```

      H = -DM*(FLOAT(I+1) - F)
      XJJ = -DM*(FLOAT(I - 5*J + 1) - F)
      FAIR = TREF - 2.*(H-MI)/1000.
      SIGMA = SIG(J) + (SIG(J+1) - SIG(J))*XJJ/1000.
      P = PRESS(J) + (PRESS(J+1) - PRESS(J))*XJJ/1000.
      TEMP = ((TH-DM)*(TEMP+OTEMP) + DM*THE)/TH
      RLM = (22.039/TAIR - (CI/TEMP))/(CI/TEMP)
      TL = TH*RLM
      CCCC WAS THE DROGUE CHUTE BEEN RELEASED? IF NOT, GO TO 100.
      IF (TL.LT.TLREL) GO TO 100
      WS = WSREF - TL - WD
      DAO = 0.
      GO TO 110
      100 WS = WSREF - TL
      110 CONTINUE

      VOL = (TH*TEMP)/(CI*P)
      DIAB = ((6./PI)*VOL)**(1./3.)
      DAB = (PI/4.)*DIAB**2 *.5
      DAS = DAB + DAO + DAM
      VE = -SQRT(ABS(WS/(.001189*SIGMA*DAS)))
      VEAV = (VE + VO)/2.
      DT = F*DM/VEAV
      T = T + DT
      VO = VE
      Q = .001189*SIGMA*VE**2
      DB = DAB*Q ; DO = DAO*Q ; DM = DAM*Q
      DS = DB + DO + DM
      WM = WS - DS

      CCCC WRITE ONE LINE OF DATA.
      WRITE (1,3)H,SIGMA,P,TAIR,RLM,DT,T,VE,Q,TH,TEMP
      WRITE (2,4)H,TL,WS,VOL,DIAB,DAS,DAB,DB,DO,DM,WM

      CCCC IF CALCULATIONS ARE DONE, GO BACK TO READ MORE DATA.
      IF (IFLAG.EQ.1) GO TO 50

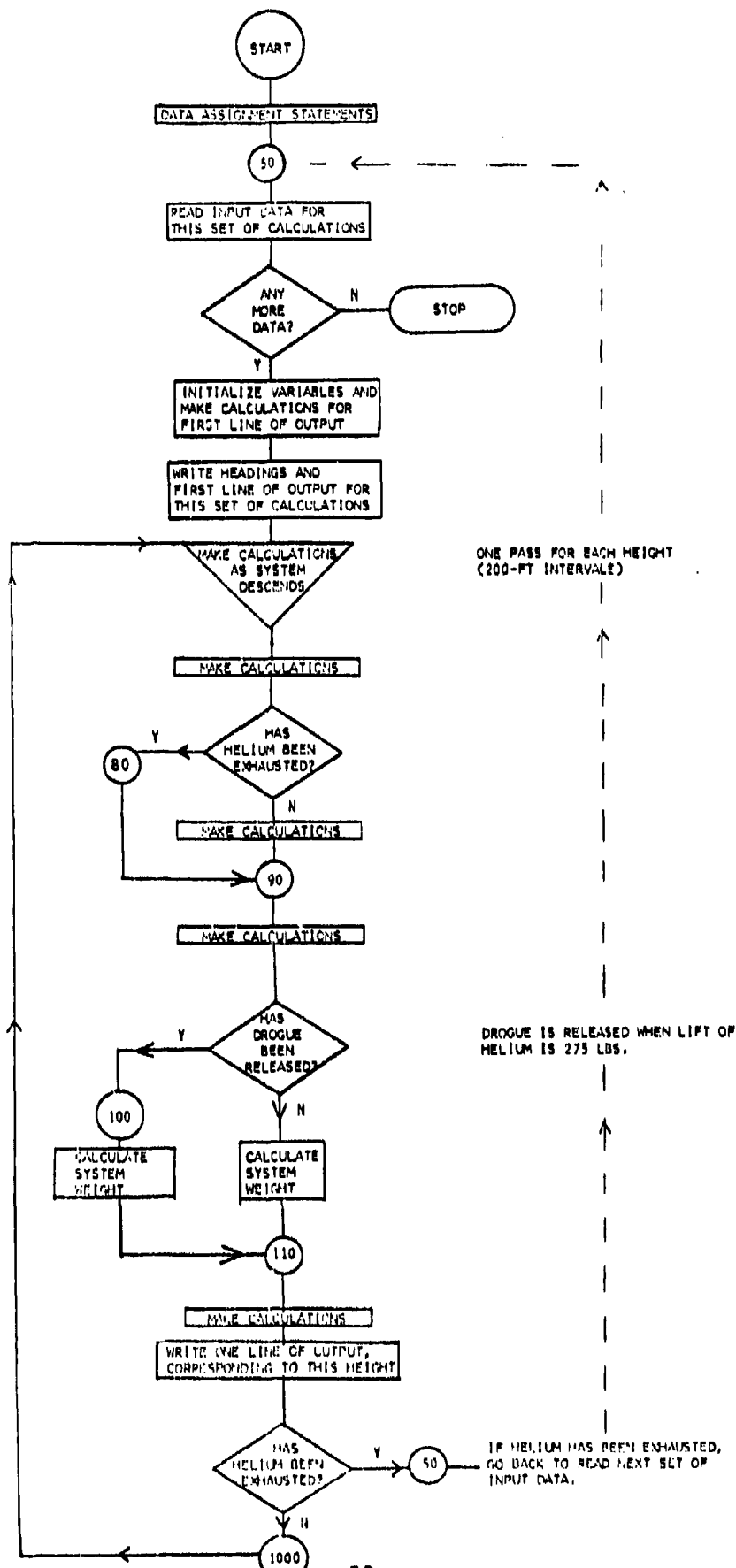
      1000 CONTINUE

      1  FORMAT (1H0," HEIGHT          SIGMA(AIR)  PRESS(ATH)    T(AIR)  ",
100  17X,"L/M*BX*D(TIME)          TIME    VEL(EQUIL)*7X,1H3,7X,"MASS(HE)",
      2  " TEMP(HE)*")
      2  FORMAT (1H0," HEIGHT          TOTAL LIFT    WT(SYS)    VOL(BALL)*
1  " DIA(BALL)    (COS0)SYS    (COS0)BALL  DRAG(BALL)  "
      2  "DRAG(DROG)  DRAG(MAIN)    WS - DS")
105  3  FORMAT (1H0,F7.0,F14.5,F12.4,F12.1,3F12.3,F12.2,F12.4,F12.3,F12.1)
      4  FORMAT (1H0,F7.0,4X,2F12.2,F12.3,6F12.2,F12.3)
      10  FORMAT (1H1,"ALBS BALLOON INFLATION CALCULATIONS",/,
1  " *PROGRAM P148",5X,A10,/)
      11  FORMAT (1H0,15X,"TEMP(HE) FROM DEWER ",3H = ,F7.1,24X,
110  1  "TEMP(AIR)          = ",F7.1,/,
      2  1H0,15X,"TRANSFER RATE",6X,2H = ,F11.4,20X,
      3  "INITIAL D(TIME)    = ",F9.2,///)
      12  FORMAT (1H1,//////,15X,"DRAG AREA MAIN CHUTE = ",F9.2,
115  1  22X,"DRAG AREA DROGUE    = ",F9.2,/,
      2  1H0,14X,"WT DROGUE AND HOWRE = ",F7.0,
      3  24X,"LIFT AT DROGUE REL = ",F9.2,///)
      13  FORMAT (1H0,F7.0,5X,F12.5,F12.4,48X,F12.2)
      14  FORMAT (1H0,F7.0,16X,F12.2,24X,F12.2,24X,2F12.2)
      STOP
      END
120

```

BEST AVAILABLE COPY

# PROGRAM P14B



**BEST AVAILABLE COPY**

end of file

22,000, 1367, 260, 1,349, 1,260.2, -39, 34, 5, 1,275, 66, 442.34, 1080.65

22400, 1367, 275, .3441, 260.2, -32.34, 5.1, 275, 55, 442.34, 1080.55

23-00, 1357, 250, 3-41, 260.2, -32.34, 5.1, 275, 66, 442.34, 1060.65

program

[illegible]

```

FEDGETM F148 (TAPE1,TAPE2,INPUT,TAPE5=INPUT)

```

end of record

COPY, TAPES, OUTPUT.

COPY, TAPE1, OUTPUT.

RECORD, TAPE 1, TAPE 2.

550.

```

LIST, FREE, SET=ZERO.

```

7TH.

REF.

2037

MANFIELD

1 1 1 1

1 1

[illegible]

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

.....

[illegible][illegible]

.....

[illegible]

.....

1. The first step in the process of identifying a problem is to recognize that a problem exists. This involves observing the current situation and comparing it to the desired state. Once a problem is identified, the next step is to define the problem clearly and concisely. This involves identifying the specific aspects of the problem that need to be addressed and determining the scope of the problem. The third step is to gather information about the problem. This involves researching the problem and identifying the causes and effects of the problem. The fourth step is to analyze the information gathered. This involves identifying the key factors that are contributing to the problem and determining the relationships between these factors. The fifth step is to develop a solution. This involves identifying the possible solutions to the problem and evaluating the pros and cons of each solution. The sixth step is to implement the solution. This involves putting the chosen solution into action and monitoring the results. The seventh step is to evaluate the solution. This involves assessing the effectiveness of the solution and determining whether the problem has been resolved. The eighth step is to communicate the results of the process. This involves sharing the findings of the process with the relevant stakeholders and providing feedback on the process itself.

[illegible][illegible]

.....

[illegible][illegible]

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

[illegible]

# ALOS BALLOON INFLATION CALCULATIONS

PROGRAM P148 05/12/77

TEMP(NE) FROM DEWER = 258.8  
TRANSFER RATE = .3441

TEMP(AIR) = 268.2  
INITIAL O/TIME = 5.18

HEIGHT	SIGMA(AIR)	PRESS(ATM)	T(AIR)	L/H	D(TIME)	TIME	VEL(EQUIL)	Q	MASS(NE)	TEMP(NE)
22400.	.49122	.4157					-39.34			
22200.	.49453	.4192	268.6	5.951	5.136	5.136	-38.54	.8737	1.755	258.8
22000.	.49790	.4227	261.8	5.951	5.222	18.358	-38.85	.8573	3.522	258.4
21800.	.50165	.4264	261.4	5.951	5.288	15.646	-37.68	.8427	5.319	258.8
21600.	.51492	.4300	261.9	5.952	5.351	28.996	-37.16	.8291	7.139	251.2
21400.	.50848	.4337	262.2	5.952	5.412	26.489	-36.74	.8161	8.908	251.8
21200.	.51187	.4373	262.6	5.952	5.473	31.842	-36.34	.8037	10.842	252.6
21000.	.51534	.4410	263.8	5.952	5.534	37.416	-35.94	.7916	12.726	252.4
20800.	.51898	.4448	263.4	5.952	5.595	43.811	-35.55	.7799	14.638	252.7
20600.	.52247	.4486	263.8	5.952	5.656	48.666	-35.17	.7684	16.555	253.1
20400.	.52583	.4523	264.2	5.952	5.717	54.384	-34.79	.7572	18.581	253.5
20200.	.52958	.4561	264.6	5.952	5.779	60.163	-34.42	.7461	20.468	253.9
20000.	.53316	.4599	265.8	5.952	5.841	66.884	-34.06	.7353	22.457	254.3
19800.	.53682	.4638	265.4	5.952	5.904	71.988	-33.69	.7245	24.467	254.7
19600.	.54047	.4677	265.8	5.952	5.968	77.871	-33.33	.7139	26.498	255.1
19400.	.54413	.4717	266.2	5.952	6.033	83.989	-32.97	.7034	28.552	255.4
19200.	.54778	.4755	266.6	5.952	6.098	90.887	-32.62	.6930	30.628	255.8
19000.	.55144	.4795	267.8	5.952	6.164	96.171	-32.27	.6827	32.726	256.2
18800.	.55513	.4835	267.4	5.952	6.232	102.483	-31.92	.6725	34.847	256.6
18600.	.55895	.4876	267.3	5.951	6.301	108.784	-31.57	.6623	36.992	256.9
18400.	.56273	.4915	268.2	5.951	6.371	115.074	-31.22	.6522	39.168	257.3
18200.	.56646	.4957	268.6	5.951	6.441	121.515	-30.88	.6421	41.352	257.7

13888.	.57871	.4997	269.8	5.958	6.513	128.829	-38.53	.6321	43.568	258.8
17887.	.57936	.5039	259.4	5.958	6.587	138.616	-36.13	.6221	43.618	258.4
17688.	.57791	.5081	269.8	5.949	6.289	148.985	-33.41	.7669	43.876	258.8
17488.	.53176	.5122	278.2	5.943	6.823	146.928	-33.11	.7537	50.246	259.2
17288.	.58501	.5164	278.6	5.553	6.894	153.822	-32.53	.7412	52.313	259.6
17888.	.58946	.5286	271.8	5.958	6.166	153.198	-32.25	.7286	54.418	268.8
16888.	.53341	.5249	271.4	5.951	6.239	165.427	-31.86	.7164	55.532	268.4
16688.	.59736	.5292	271.8	5.951	6.314	171.741	-31.48	.7848	58.678	268.8
16488.	.68131	.5336	272.2	5.951	6.391	178.132	-31.18	.6917	68.851	261.1
16288.	.68526	.5379	272.6	5.951	6.469	184.682	-30.72	.6794	63.858	261.5
16888.	.68321	.5422	273.8	5.951	6.558	191.152	-30.35	.6676	65.276	261.9
15888.	.61326	.5467	273.4	5.951	6.632	197.784	-29.37	.6547	67.538	262.3
15688.	.61731	.5512	273.8	5.958	6.717	204.581	-29.58	.6424	69.812	262.7
15488.	.62436	.5556	274.2	5.958	6.884	211.385	-29.28	.6381	72.124	263.8
15288.	.62541	.5681	274.6	5.949	6.893	218.199	-28.82	.6177	74.465	263.4
15888.	.62946	.5646	275.8	5.949	6.985	225.184	-28.44	.6854	76.837	263.8
14888.	.63361	.5692	275.4	5.948	7.888	232.264	-28.86	.5938	79.241	264.1
14688.	.63776	.5738	275.8	5.948	7.178	239.442	-27.57	.5856	81.677	264.5
14488.	.64192	.5784	276.2	5.947	7.279	246.721	-27.28	.5682	84.147	264.8
14288.	.64687	.5838	276.6	5.946	7.383	254.184	-26.38	.5557	86.651	265.2
14088.	.65122	.5876	277.8	5.945	7.491	261.594	-26.58	.5431	89.192	265.5
13888.	.65448	.5924	277.4	5.944	7.682	269.197	-26.11	.5386	91.769	265.9
13588.	.65374	.5972	277.9	5.943	7.718	276.915	-25.71	.5179	94.385	266.2
13488.	.65239	.6013	278.2	5.941	7.839	284.753	-25.32	.5852	97.841	266.5
13288.	.66725	.6067	278.6	5.948	7.963	292.716	-24.31	.4925	99.736	266.3
13883.	.67145	.6114	279.9	5.939	7.978	3.9.695	-24.51	.4758	102.448	267.2

DRAG AREA MAIN CHUTE = 1838.55  
WT DROGUE AND HOBBS = 65.

DRAG AREA DROGUE = 442.34  
LIFT AT DROGUE REL = 275.00

HEIGHT	TOTAL LIFT	WT(SYS)	VOL (BALL)	DIA (BALL)	(CDS9) SVS	(CDS9) BALL	DRAG (BALL)	DRAG (DROG)	DRAG (MAIN)	WS - DS
22480.	16.44	1367.00	344.140	0.69	1522.99	29.69	25.34	386.47	944.15	.000
22200.	28.95	1346.84	626.037	12.94	1578.01	47.82	48.31	375.24	926.49	.000
22100.	31.66	1335.34	1020.778	12.52	1584.59	61.60	51.31	372.76	910.67	.000
21800.	42.43	1324.51	1371.078	13.70	1597.68	74.61	61.85	366.73	895.93	9.006
21400.	53.45	1313.55	1712.022	14.04	1609.53	86.54	78.62	361.00	881.93	.000
21200.	64.53	1302.47	2053.941	15.77	1620.67	97.68	78.50	355.49	868.40	.000
21000.	75.74	1291.26	2394.417	16.58	1631.13	108.19	85.55	350.16	855.45	.000
20800.	87.08	1279.92	2733.528	17.35	1641.17	119.10	92.17	344.97	842.78	0.000
20600.	98.54	1268.46	3071.856	18.04	1650.73	127.74	96.16	339.90	830.40	-.000
20400.	110.13	1256.87	3409.446	18.67	1659.93	135.94	103.49	334.93	818.25	.000
20200.	121.84	1245.16	3746.437	19.27	1668.81	145.82	108.00	330.85	806.32	.000
20000.	133.67	1233.33	4082.778	19.83	1677.41	154.42	113.54	325.23	794.56	.000
19800.	145.64	1221.36	4417.276	20.36	1685.73	162.74	117.31	320.47	782.96	.000
19600.	157.73	1209.27	4751.011	20.86	1693.83	170.84	121.37	315.88	771.51	.000
19400.	169.35	1197.85	5084.212	21.33	1701.73	179.74	125.73	311.16	760.17	0.000
19200.	182.30	1186.78	5416.039	21.79	1709.44	186.45	129.22	306.56	748.93	0.000
19000.	194.78	1172.22	5749.145	22.23	1716.99	194.80	132.45	301.57	737.70	.000
18800.	207.48	1159.68	6079.513	22.64	1724.35	201.35	135.41	297.47	726.72	.000
18600.	220.15	1146.85	6409.464	23.05	1731.57	208.58	138.15	292.97	715.73	0.000
18400.	233.84	1133.96	6739.033	23.44	1738.66	215.57	140.56	288.50	704.80	.000
18200.	245.77	1121.93	7068.482	23.81	1745.53	222.64	142.37	284.84	693.32	.000

15000.	259.24	1107.76	7397.712	24.17	1757.50	229.51	145.07	279.61	603.08	0.000
17000.	277.56	1096.64	7728.724	24.53	1759.21	236.22	146.36	275.19	672.30	0.000
17500.	286.52	1014.90	8051.517	24.87	1323.43	242.84	185.23	0.00	828.75	0.000
17400.	298.30	1002.10	8357.906	25.18	1329.61	248.96	107.53	0.00	916.47	0.000
17200.	311.26	909.74	8645.716	25.40	1335.29	254.64	103.74	0.00	801.00	0.000
17000.	323.75	977.74	8933.045	25.74	1346.92	260.27	109.68	0.00	747.56	0.000
16800.	336.48	964.68	9219.837	26.02	1346.44	265.79	190.42	0.00	774.10	0.000
16600.	349.19	951.81	9506.122	26.20	1351.92	271.27	190.98	0.00	768.03	0.000
16400.	362.13	938.87	9792.031	26.54	1357.34	276.69	191.35	0.00	747.49	0.000
16200.	375.21	925.79	10078.021	26.80	1362.73	282.00	191.63	0.00	734.15	0.000
16000.	388.45	912.55	10367.797	27.05	1368.07	287.42	191.72	0.00	720.03	0.000
15800.	401.95	899.15	10653.133	27.30	1373.32	292.67	191.62	0.00	707.93	0.000
15600.	415.41	885.59	10939.140	27.54	1378.56	297.89	191.37	0.00	694.22	0.000
15400.	429.13	871.07	11225.932	27.78	1383.72	303.07	190.96	0.00	680.90	0.000
15200.	443.03	857.97	11513.615	28.02	1388.88	308.23	190.40	0.00	667.57	0.000
15000.	457.10	843.98	11802.301	28.25	1394.01	313.36	189.78	0.00	654.20	0.000
14800.	471.34	829.66	12089.554	28.48	1399.07	318.42	188.02	0.00	640.03	0.000
14600.	485.77	815.23	12377.975	28.70	1404.11	323.46	187.00	0.00	627.42	0.000
14400.	500.39	800.61	12667.761	28.92	1409.16	328.49	186.53	0.00	613.97	0.000
14200.	515.21	785.75	12958.865	29.14	1414.16	333.51	185.32	0.00	600.47	0.000
14000.	530.23	770.77	13251.605	29.36	1419.16	338.51	183.35	0.00	586.92	0.000
13800.	545.45	755.55	13544.351	29.57	1424.03	343.44	182.21	0.00	573.34	0.000
13600.	560.89	740.11	13834.073	29.78	1429.01	348.36	180.42	0.00	559.69	0.000
13400.	576.55	724.45	14128.143	29.99	1433.93	353.28	178.69	0.00	545.97	0.000
13200.	592.44	708.56	14426.130	30.20	1438.05	358.20	176.49	0.00	532.17	0.000
13000.	608.35	692.65	14719.906	30.41	1443.71	363.06	174.13	0.00	518.00	0.000

## Nomenclature

### Program 14B

C1	=3.0413, used in equation of state (English units)
DAB	Drag area of the balloon, $(C_D S_o)_{\text{balloon}}$
DAD	Drag area of the drogue, $(C_D S_o)_{\text{drogue}}$
DAM	Drag area of the main chute, $(C_D S_o)_{\text{main}}$
DAS	Drag area of the whole system, $(C_D S_o)_{\text{system}}$
DB	Drag of the balloon, $D_B$
DD	Drag of the drogue, $D_D$
DH	Increment of height, $\Delta H$
DIAB	Diameter of the balloon, $d_b$
DM	Mass of helium transferred in time, $\Delta t$
DS	Drag of the system, $D_S$
DT	Increment of time, $\Delta t$ , during which system drops a height $\Delta H$
DTEMP	Increase in temperature, $\Delta T$ , of helium due to adiabatic heating from the balloon's dropping a height $\Delta H$ (200 ft). $DTEMP = .8^\circ / 200 \text{ ft}$ or $4^\circ / 1000 \text{ ft}$
F	Interpolation factor used to calculate last line of output
H	Height, $H$
HI	Initial height, $H_1$
IFLAG	Flag used to indicate whether calcula- tions have been completed

## NOMENCLATURE

I	Number of intervals of height from ground, i.e., $I = H/\Delta H$
II	Index for DØ loop
ITØP	Number of height intervals of the initial height from the ground, i.e., $ITØP = H_1/\Delta H$
J	Number of height intervals from ground in thousands of feet.
JJ	Number of height intervals from J to I
P	Pressure (P) at height H
PI	$\pi$
PRESS	Array containing values of pressure at 1000 ft. intervals, used in the calculation of P
Q	Dynamic pressure, $q = \frac{1}{2}\rho v^2$
RLM	Lift to mass ratio (L/M) of helium in the balloon.
SIG	Array containing values of $\sigma = \rho/\rho_0$ at 1000 ft. intervals, used in the calculation of SIGMA
SIGMA	Ratio of $\sigma = \rho/\rho_0$ at height H
T	Time, t
TAIR	Temperature of the air at height H
TEMP	Temperature of the helium in the balloon at height H
THE	Temperature of helium from the dewer
TL	Total lift at height H

TLREL	Total lift when drogue is to be released.
TN	Total mass at height H
TNHE	Total mass of helium to be transferred to balloon
TNM	Temporary storage for TM
TR	Transfer rate of helium
TREF	Temperature of air at $H_1$
VE	Equilibrium velocity ( $v_o(H_1)$ ) of system
VEAV	Average velocity over interval
VØL	Volume of the balloon
VO	Velocity at end of preceding interval
WD	Weight of the drogue and associated hardware
WS	Weight of the system less the total lift
WSREF	Initial weight of the system
WW	= (WS - DS) and should always be very close to zero
XJJ	Difference in height from H to next lowest 1000-ft level

## Adiabatic Heating of the Gas in the Balloon

As the balloon descends into a thicker and thicker atmosphere, the balloon contracts due to the greater pressure causing the gas in the balloon to undergo a certain amount of adiabatic heating. This is known to be  $4^{\circ}\text{K}$  per 1000 ft of descent and is essentially constant throughout the region of interest.

In program P14B calculations done every 200 ft, and through this distance the gas (already in the balloon, not in the dewer) will heat up by  $.8^{\circ}\text{K}$ . The temperature and transfer rate of the gas entering the balloon are assumed to be constant, and the gas in the balloon is assumed to be at all times in equilibrium, i.e., the temperature of the gas is uniform throughout the balloon. The relationship connecting the temperature, pressure, and volume of the gas is taken to be the equation of state for an ideal gas expressed as:

$$V = \frac{mT}{3.0413 P}$$

where  $V$  is in cu ft,  $m$  in grams,  $T$  in  $^{\circ}\text{K}$ , and  $P$  in atmospheres.

In each 200-ft interval the system drops a height of 200 ft in a time  $\Delta t$ , which is computed elsewhere in the program. During this time a mass  $\Delta m$  of helium at temperature  $T_{\text{He}}$  is transferred at a uniform transfer rate  $r$ , and we have:

$$\Delta m = r \Delta t$$

Also, the mass  $m_0$  of helium already in the balloon is heated  $.8^\circ$  from its original temperature  $T_0$  to a temperature of  $T_0 + .8^\circ$ . The mass  $m$  of helium entering the balloon is at temperature  $T_{He}$  and mixes to form a new temperature  $T$  inside the balloon such that:

$$T = \frac{m_0(T + .8) + \Delta m T_{He}}{m_0 + \Delta m}$$

The new volume of the balloon is:

$$V = \frac{(m + \Delta m)T}{3.0413 P}$$

where  $P$  is the pressure at the new height.

## References

1. Carten, Andrew S. Jr., 1976, The Flight Test Aspects of the Air-Launched Balloon System (ALBS) Development Program, AFGL-TR-76-0196.

## II. VOR Positioning Program

### A. Introduction

The position of a free balloon after launch is found by tracking the balloon from two or more VOR stations which measure the direction of the balloon with respect to magnetic north. The position of the balloon is then found by plotting these bearings on a map of that region.

A program has been written for the HP-9810A programmable calculator which will calculate the balloon position from the station locations and their bearings on the balloon. Calculations are based on spherical geometry, which is exact (for a perfectly spherical earth), and, therefore, errors due to the plotting on the map and to distortions in the projection of the map are eliminated.

The mathematics are described in Section B.

The program stores the coordinates of as many as 8 VOR stations at one time. In this way the path of the balloon can be followed over a longer distance without having to change the station coordinates. The program works as follows:

After the latitudes, longitudes, and declinations of the 8 stations have been input, the program will then request magnetic bearings from any three of those stations. The user will enter the number of each station he has

chosen and its corresponding bearing. Taking the stations two at a time, the program will then calculate intersection points among the three stations selected.

After the coordinates of these intersection points have been calculated and printed, the program will request a new set of bearings. These new bearings need not necessarily be from the same stations previously chosen; any 3 of the 8 may be selected.

A complete description on how to use the program is given in Section C.

## B. Mathematics

### 1. Introduction

The projection on the earth of the line of sight from a VOR station to the balloon follows a great-circle path. Therefore, the balloon position can be found by calculating the location of the point of intersection of the two great circles which correspond to the lines of sight from fixes from the two given VOR stations.

Inputs to the calculation are the latitudes, longitudes, and declinations of the two stations and the directions of the balloon from the stations with respect to magnetic north. The declination is used to change the magnetic direction to a compass heading with respect to true north.

For each station, these quantities are used to form

one vector which points from the station to the balloon, and another vector which points from the center of the earth to the station. Taking the cross product of these two vectors produces a vector which is perpendicular to the plane of that great circle which is the projection of the line of sight from that station to the balloon. In other words, one set of station coordinates and a bearing from that station produces a vector which is normal to the plane of that great circle which corresponds to the line of sight from that station to the balloon.

Taking the cross product of two of these normal vectors produces a vector which points from the center of the earth towards the point of intersection of the corresponding two great circles, i.e., it points along the line of intersection of the two great-circle planes. From this vector one can compute the latitude and longitude of the balloon.

## 2. Input and Output

The input to the calculation is the latitudes, longitudes, declinations, and magnetic bearings of the balloon of two stations.

The latitudes are north latitudes.

The longitudes are input to and output from the program as west longitudes. However, for mathematical convenience, within the program and in the calculations which follow,

east longitude is used in order to be consistent with a right-handed Cartesian coordinate system.

In the program the magnetic bearings are converted to bearings with respect to true north by adding to each its corresponding declination (expressed as positive for an easterly declination).

The north latitude and west longitude of the balloon position are printed by the program.

### 3. Nomenclature

$O$	is the center of the earth
$A, C$	are two VOR stations
$B$	is the position of the balloon
$\theta_A, \theta_B, \theta_C$	are the north latitudes of positions A, B, and C, respectively
$\lambda_A, \lambda_B, \lambda_C$	are the east longitudes of positions A, B, and C, respectively
$\vec{OA}, \vec{OB}, \vec{OC}$	are unit vectors from O to A, B, and C, respectively. These vectors are local verticals
$\vec{AN}, \vec{BN}$	are unit vectors at A and B, respectively, which point due north, i.e., these vectors are local horizontals pointing north
$\vec{AE}, \vec{BE}$	are unit vectors at A and B, respectively, which point due east, i.e., local horizontals pointing east

$\eta_A, \eta_B$  are bearings on the balloon with respect to true north from stations A and C, respectively

$\overrightarrow{AB}, \overrightarrow{CB}$  are unit vectors which point from A and C, respectively, along those great-circle paths which are in the direction of the balloon B, i.e., local horizontals pointing in the direction of the balloon

$\vec{n}_A, \vec{n}_B$  are vectors which are normal to the great-circle planes specified by the vectors  $\overrightarrow{AB}$  and  $\overrightarrow{CB}$ , respectively

#### 4. Equations

a. The first step is to form the vectors  $\overrightarrow{OA}$ ,  $\overrightarrow{ON}$ , and  $\overrightarrow{OE}$  for station A. The vectors  $\overrightarrow{OC}$ ,  $\overrightarrow{CN}$ , and  $\overrightarrow{CE}$  will then be constructed in a similar fashion. The vectors are expressed in terms of their x, y, and z components respectively. The origin of this Cartesian coordinate system lies at the center of the earth; the z-axis points towards the north pole; the x and y axes lie in the plane of the equator and point toward the  $0^\circ$  and  $90^\circ$  meridians, respectively.

The x, y, and z components of these vectors can be expressed in terms of the latitude  $\theta_A$  and longitude  $\lambda_A$  of station A.

Looking at Figures 1 and 2, one can see that the x, y, and z components, respectively, of these vectors are:

$$\overrightarrow{OA} = (\cos\theta_A \cos\lambda_A, \cos\theta_A \sin\lambda_A, \sin\theta_A)$$

$$\overrightarrow{AN} = (-\sin\theta_A \cos\lambda_A, -\sin\theta_A \sin\lambda_A, \cos\theta_A)$$

$$\overrightarrow{AE} = (-\sin\lambda_A, \cos\lambda_A, 0)$$

The vectors  $\overrightarrow{OC}$ ,  $\overrightarrow{CN}$ , and  $\overrightarrow{CE}$  are constructed similarly, and their components can be found by substituting  $\theta_C$  for  $\theta_A$  and  $\lambda_C$  for  $\lambda_A$  in the vectors given above.

b. The next step is to form the vector  $\overrightarrow{AB}$  which points from A along the great-circle path which is the projection of the line of sight from A to B. In Figure 3 is a diagram of the local horizontal plane at A. From this we see that:

$$\overrightarrow{AB} = \overrightarrow{AN} \cos\eta_A + \overrightarrow{AE} \sin\eta_A$$

Expanding this to find the x, y, and z components of  $\overrightarrow{AB}$ , we have:

$$\begin{aligned} \overrightarrow{AB} = & (-\sin\theta_A \cos\lambda_A \cos\eta_A - \sin\lambda_A \sin\eta_A, \\ & -\sin\theta_A \sin\lambda_A \cos\eta_A + \cos\lambda_A \sin\eta_A, \\ & \cos\theta_A \cos\eta_A) \end{aligned}$$

The vector  $\overrightarrow{CB}$  is constructed similarly, and its components can be found by substituting  $\theta_C$  for  $\theta_A$ ,  $\lambda_C$  for  $\lambda_A$  and  $\eta_C$  for  $\eta_A$  in the above equations.

c. The next step is to form the vector  $\overrightarrow{n_A}$  which is normal to that great-circle plane which contains the line of sight from station A to balloon B. This vector can be formed by crossing any two vectors which lie in the plane (and are not parallel). The vectors  $\overrightarrow{OA}$  and  $\overrightarrow{AB}$  lie in this plane, and we have:

$$\vec{n}_A = \vec{OA} \times \vec{AB}$$

$$\begin{aligned} (\vec{n}_A)_x &= (\vec{OA})_y (\vec{AB})_z - (\vec{OA})_z (\vec{AB})_y \\ &= \sin\lambda_A \cos\eta_A - \sin\theta_A \cos\lambda_A \sin\eta_A \end{aligned}$$

$$\begin{aligned} (\vec{n}_A)_y &= (\vec{OA})_z (\vec{AB})_x - (\vec{OA})_x (\vec{AB})_z \\ &= -\cos\lambda_A \cos\eta_A - \sin\theta_A \sin\lambda_A \sin\eta_A \end{aligned}$$

$$\begin{aligned} (\vec{n}_A)_z &= (\vec{OA})_x (\vec{AB})_y - (\vec{OA})_y (\vec{AB})_x \\ &= \cos\theta_A \sin\eta_A \end{aligned}$$

The vector  $\vec{n}_B$  is constructed similarly, and its components can be found by substituting  $\theta_C$  for  $\theta_A$ ,  $\lambda_C$  for  $\lambda_A$  and  $\eta_C$  for  $\eta_A$  in the above equations.

d. Taking the cross product  $\vec{V}$  of the vectors  $\vec{n}_A$  and  $\vec{n}_B$  produces a vector which points along the line of intersection of the two great-circle planes. This line of intersection passes through the center of the earth and the balloon. The vector formed will point either from the center of the earth to the balloon towards a north latitude or in the opposite direction towards a south latitude. The components of  $\vec{V}$  are:

$$v_x = (\vec{n}_A)_y (\vec{n}_B)_z - (\vec{n}_A)_z (\vec{n}_B)_y$$

$$v_y = (\vec{n}_A)_z (\vec{n}_B)_x - (\vec{n}_A)_x (\vec{n}_B)_z$$

$$v_z = (\vec{n}_A)_x (\vec{n}_B)_y - (\vec{n}_A)_y (\vec{n}_B)_x$$

In the case that  $\vec{V}$  points towards a south latitude, we can turn the vector around by making the transformation  $\vec{V} \rightarrow -\vec{V}$ .

e. Even though  $\vec{V}$  now points in the direction of  $\vec{OB}$ , it is not necessarily a unit vector. To form the unit vector,

$\vec{v}$  must be divided by its length and we have:

$$\vec{OB} = \vec{v} / |\vec{v}|$$

$$\text{where } |\vec{v}| = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

6) Looking back at Figures 1 and 2, the coordinates of the balloon  $\theta_B$  and  $\lambda_B$  can be found from  $\vec{OB}$  or  $\vec{v}$  by:

$$\theta_B = \sin^{-1}[(\vec{OB})_z] = \sin^{-1}\left(\frac{v_z}{|\vec{v}|}\right)$$

$$\lambda_B = \cos^{-1}\left[\frac{(\vec{OB})_x}{\cos \theta_B}\right] = \cos^{-1}\left[\frac{v_x}{|\vec{v}| \cos \theta_B}\right]$$

## C. The Program

### 1. Introduction

The following is a step-by-step description of how to use the VOR positioning program. A sample output, a listing, a flow chart, and an explanation of the organization of the memory are also provided in Figures 4 - 7, respectively. Supplementary information about the program is given which enables the user, when data has been entered incorrectly, to correct the mistake without having to go back to the beginning of the program.

### 2. How to Use the Program

Press END, CONTINUE.

The program then asks for the number of stations to be put into the calculator. The program can handle up to 8 stations. The user puts this number into the x register and then presses CONTINUE.

The program then prints a station number, starting at station 1 and going up to the number of stations requested

in the previous step, and requests the latitude, longitude, and declination, respectively, of that station. For each of these variables, enter the number of degrees in z, minutes in y, and seconds in x, and then press CONTINUE.

Latitude is input as north latitude, longitude as west longitude, and declination is input as a positive quantity for an easterly declination and as a negative quantity for a westerly declination.

After reading these quantities for a particular station, the program goes on to the next station, or, if the last station has just been input, it goes on to the next step.

The program then asks for the time of day. This is done so that there will be a record of the time that the VOR readings were taken. The user puts the time into the x register in the following way: 14:45 is put in as 14.45, etc. The user then presses CONTINUE.

The program then asks for bearings from any three of the stations, called 1ST, 2ND, and 3RD stations, respectively. For each of the three stations to be selected, enter the number of the station required in the y register and its corresponding magnetic bearing, expressed in decimal degrees, in the x register.

The program then prints the coordinates of the balloon location calculated using the 1st and 2nd stations, then the 1st and 3rd stations, and finally the 2nd and 3rd stations. For each station pair the latitude and longitude

are printed in degrees, minutes, and seconds.

The program then asks for a new time and then new station numbers and bearings. Again, any three stations may be selected, and these need not be the same ones which were selected previously. After each set of bearings has been input, and the balloon positions calculated, the program goes back to ask for a new time and a new set of station numbers and bearings.

A sample output is shown in Figure 4. All variables which the user must supply have an asterisk placed beside them. Note that all variables input by the user are printed on the paper tape immediately after being entered.

### 3. Supplementary Information

In order to help the user understand (and possibly modify) the program, a listing of the program is given in Figure 5 and a flow chart in Figure 6.

In the case that, after the station data have been entered, it is discovered that a station coordinate was entered incorrectly, or it is necessary that another station be substituted or added, it is usually more convenient to be able to enter the information directly into the memory rather than having the program do it. (For the program to do this requires that all of the

information be reentered.) This requires a better knowledge of the memory and program organization. The organization of the memory is shown in Figure 7.

To put a number into a particular memory location, put the number into the x register, press  $x \rightarrow$  (XTO) followed by the three-digit memory location. Since the coordinates entered in this program are always expressed in terms of degrees, minutes, and seconds, the user must first change this to decimal degrees before entering it into memory. In this case, put the numbers of degrees, minutes, and seconds into the z, y, and x registers, respectively, press K, 6 to convert to decimal degrees in the x register, and then press  $x \rightarrow$ , followed by the three-digit memory address.

For station number i,  $i = 1$  to 8, the latitude  $\theta$ , longitude  $\lambda$ , and declination  $\eta$  are put into memory locations  $5i+5$ ,  $5i+6$ , and  $5i+7$ , respectively. The number of stations which are being stored in the memory is kept in memory address 000.

If a bearing is entered incorrectly, press GTO, 0, 2, 5, 0, and CONTINUE. The program will then ask for a time followed by three new station numbers and their corresponding bearings. The old station numbers and bearing are replaced.

#### D. Comparison of VOR Data with Radar Data

Using data from a particular balloon flight for which both VOR and radar data were available, a comparison of results using these two sets of data was made. Radar data are considered to produce substantially more accurate results than VOR data and, therefore, are suitable for determining the accuracy of the VOR data.

Errors in VOR positioning can result from a number of sources: 1) the error ( $\Delta\eta$ ) in the magnetic bearing ( $\eta$ ) of the target as viewed by the VOR station in question, 2) interference from other radio signals or mountains, and 3) the line of sight being too close to the horizon. The error in the bearing is the only type of error which will be discussed here. Errors due to the other two sources are highly unpredictable and would probably have to be measured empirically.

The error in positioning ( $E$ ) due to one VOR station alone at a distance  $d$  from the target, assuming the bearing of the other station used for the fix is exact, is:  
 $E = d \tan(\Delta\eta)$ , or for small  $\Delta\eta$ ,  $E = d(\Delta\eta)$ . The maximum error in a VOR bearing is known to be  $\pm 1/2^\circ$ . Errors ( $\vec{E}_1$  and  $\vec{E}_2$ ), due to the errors in the bearings of both of the VOR stations used to produce a given fix, add vectorially to produce the total error  $\vec{E} = \vec{E}_1 + \vec{E}_2$ . This is shown in Figure 8.

When the angle  $\alpha$ , the angle between the lines of sight from two given VOR stations, approaches  $180^\circ$ , i.e., when the balloon is very close to the line joining the two VOR stations, the total error ( $\vec{E}_1 + \vec{E}_2$ ) can become very large even though the bearings themselves are accurate, i.e.,  $\Delta n_1$  and  $\Delta n_2$  are small. Conversely, an intersection angle of  $90^\circ$  between the lines of sight is optimum. This is shown in Figure 9. The shaded areas show where the balloon might be for each of the two fixes A and B, assuming an error of  $\pm 1/2^\circ$  in each of the bearing-angle measurements. The centers of the shaded areas are the positions where the VOR predicts that the balloon is located. Note that for position B the fact that  $\alpha$  is close to  $180^\circ$  can lead to a large error in the prediction of the balloon position.

Both radar and VOR data were available on balloon flight H75-4, which took place on February 7, 1975. VOR data were available from the following stations: 1) Truth or Consequences, 2) Deming, 3) Newman, Texas, 4) Holloman, 5) Pinon, 6) Hudspeth, Texas, 7) Roswell, and 8) Pecos, Texas. These stations and the position of the radar are shown on a map of the area in Figure 10. Balloon positions and their corresponding times are shown throughout the flight.

During this flight balloon positions were computed using Truth or Consequences, Holloman, Pinon, and Roswell. The other stations were too far away to provide accurate results.

Since  $E = d \tan \Delta n$ , the error is proportional to the distance of the station from the target. Furthermore, the farther away the station is from the balloon, the closer to the horizon the balloon appears.

Larger discrepancies ( 2 to 4 nm) occurred at the beginning of the flight (before 9:14) when the balloon had not yet reached flight altitude and was therefore too close to the horizon to get a good fix. The radar was much closer to the balloon during this time, and its results are probably accurate.

Later in the flight (10:35 and after), discrepancies of 2 to 5 nm were seen. At this point the balloon was about halfway between Roswell and Pinon, so that  $\alpha$  was close to  $180^\circ$ . Therefore, these two stations could not be used together to get a good fix. Holloman and Truth or Consequences were at this time quite far away (60 and 120 nm, respectively) and were also looking over a mountain range. Hence, using either one of these with either Roswell or Pinon also tended to produce larger errors than usual because of both the distance, increasing the error and making the balloon appear close to the horizon, and the interference produced by the mountains. This seems to have been in fact the case, because the fixes using Holloman were consistently about 3 nm to the south, whereas the fixes using Truth or Consequences were consistently about 3 nm to the north. Note

that the radar data could also have been influenced by the mountains and the balloon's being too close to the horizon. However, the fact that Holloman predicted positions were consistently 6 nm south of those predicted by Truth or Consequences shows that the VOR data themselves were inconsistent. During this part of the flight Carlsbad could have provided a good fix, but data from it were not available.

## LIST OF FIGURES

1. CROSS SECTION OF THE EARTH CONTAINING POINTS O,A, AND THE NORTH POLE
2. PROJECTIONS OF  $\overrightarrow{AN}$ ,  $\overrightarrow{AE}$ , AND  $\overrightarrow{OA}$  IN THE PLANE OF THE EQUATOR
3. VECTORS IN THE PLANE TANGENT TO THE EARTH AT A
4. SAMPLE OUTPUT
5. LISTINGS OF VOR PROGRAM
6. FLOW CHART OF VOR PROGRAM
7. ORGANIZATION OF MEMORY USED FOR VOR PROGRAM
8. ERROR IN BALLOON POSITION FROM VOR FIXES
9. EFFECT OF  $\alpha$  ON THE ERROR IN BALLOON POSITION
10. MAP SHOWING BALLOON FLIGHT H75-4

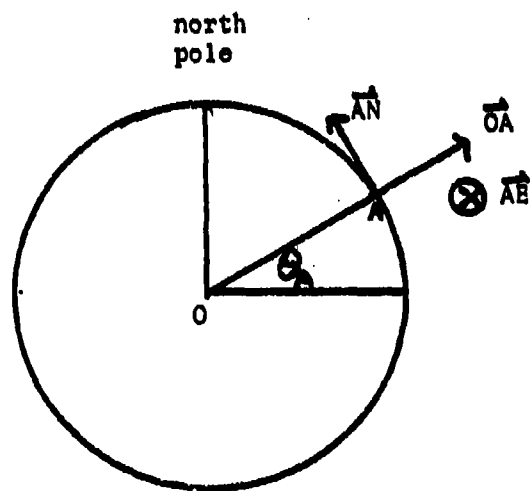


Figure 1. Cross Section of the Earth Containing Points O, A, and the North Pole.

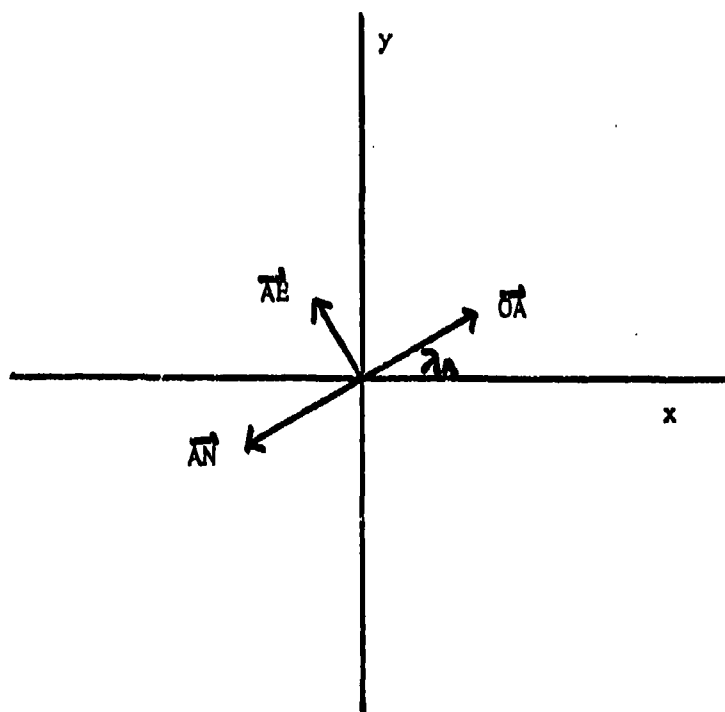
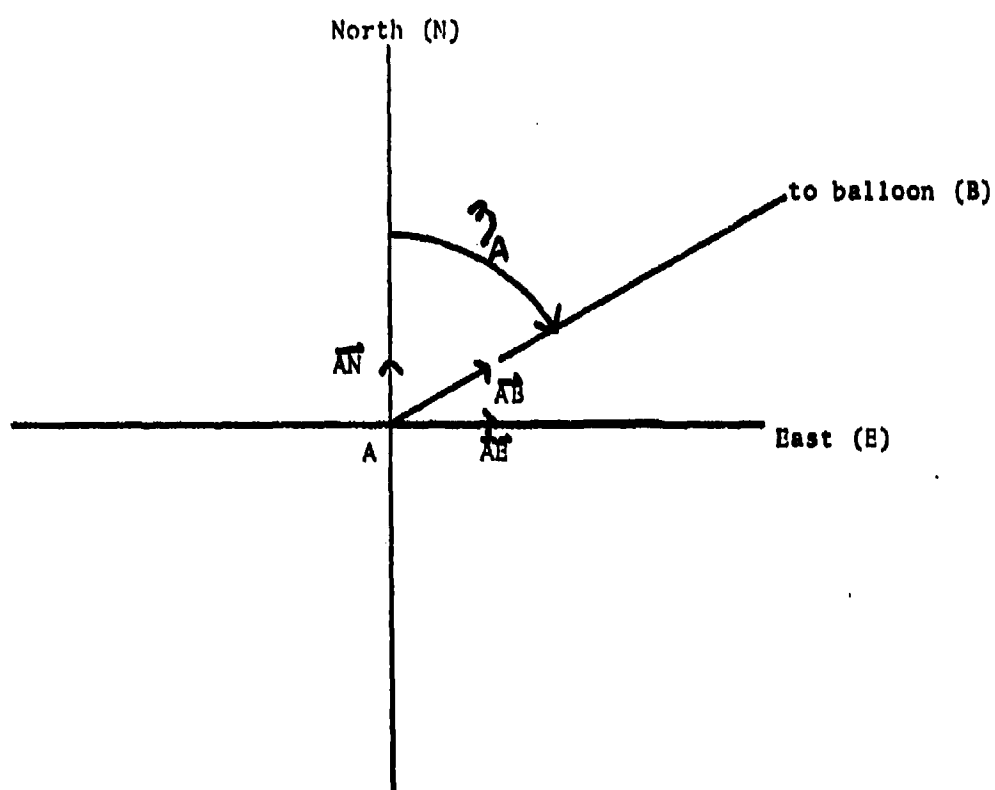


Figure 2. Projections of  $\vec{AN}$ ,  $\vec{AE}$ , and  $\vec{OA}$  in the Plane of the Equator.



$$\vec{AB} = \vec{AN} \cos \gamma_A + \vec{AE} \sin \gamma_A$$

Figure 3. Vectors in the Plane Tangent to the Earth at A.

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Fig.4 Sample output

DEGREES  
MINUTES  
SECONDS

# OF STATIONS

3.0000\*

STATION

1.0000

LATITUDE

32.0000\*

59.0000\*

26.0000\*

LONGITUDE

106.0000\*

7.0000\*

50.0000\*

DECLINATION

12.0000\*

15.0000\*

0.0000\*

STATION

2.0000

LATITUDE

32.0000

51.0000

45.0000

LONGITUDE

105.0000

18.0000

17.0000

DECLINATION

11.0000

40.0000

0.0000

STATION

3.0000

LATITUDE

32.0000

20.0000

15.0000

LONGITUDE

104.0000

37.0000

15.0000

DECLINATION

11.0000

54.0000

0.0000

TIME

11.1000\*

BEARINGS

1ST STATION

1.0000\*

90.0000\*

2ND STATION

2.0000\*

33.0000\*

3RD STATION

3.0000\*

201.0000\*

BALLOON POS.

1ST AND 2ND

LATITUDE

32.0000

46.0000

0.8620

LONGITUDE

105.0000

1.0000

24.9361

1ST AND 3RD

LATITUDE

32.0000

46.0000

22.3124

LONGITUDE

105.0000

3.0000

16.8366

2ND AND 3RD

LATITUDE

32.0000

40.0000

58.4405

LONGITUDE

105.0000

7.0000

23.4725

TIME

PROGRAM NAME \_\_\_\_\_

NUMBER \_\_\_\_\_

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0000--CLR		0050--FMT		0100--LBL		0150--O		0200--LBL		0250--FMT	
0001--CNT		0051--CNT		0101--I		0151--H		0201--A		0251--FMT	
0002--CNT		0052--CNT		0102--CNT		0152--G		0202--CNT		0252--CLR	
0003--CNT		0053--STP		0103--CNT		0153--I		0203--CNT		0253--CLR	
0004--CNT		0054--PNT		0104--FMT		0154--XTO		0204--RUP		0254--CLR	
0005--CNT		0055--PNT		0105--FMT		0155--1/X		0205--PNT		0255--XTO	
0006--CNT		0056--PNT		0106--YTO		0156--D		0206--RUP		0256--I	
0007--CNT		0057--XTO		0107--XTO		0157--E		0207--PNT		0257--M	
0008--CNT		0058--O		0108--A		0158--FMT		0208--RUP		0258--E	
0009--CNT		0059--O		0109--XTO		0159--CNT		0209--PNT		0259--FMT	
0010--FMT		0060--O		0110--I		0160--CNT		0210--PNT		0260--STP	
0011--FMT		0061--CNT		0111--O		0161--STP		0211--CNT		0261--PNT	
0012--D		0062--I		0112--N		0162--CNT		0212--CNT		0262--PNT	
0013--E		0063--XTO		0113--FMT		0163--CNT		0213--K		0263--CLR	
0014--G		0064--a		0114--CNT		0164--GTO		0214--6		0264--FMT	
0015--a		0065--CNT		0115--CNT		0165--S/R		0215--CNT		0265--FMT	
0016--E		0066--CNT		0116--a		0166--LBL		0216--CNT		0266--O	
0017--E		0067--CNT		0117--PNT		0167--A		0217--CNT		0267--E	
0018--YTO		0068--CNT		0118--UP		0168--CNT		0218--CNT		0268--A	
0019--CLR		0069--CNT		0119--5		0169--CNT		0219--CNT		0269--a	
0020--M		0070--GTO		0120--X		0170--FMT		0220--CNT		0270--I	
0021--I		0071--S/R		0121--+		0171--FMT		0221--CNT		0271--N	
0022--H		0072--LBL		0122--YTO		0172--D		0222--CNT		0272--G	
0023--1/X		0073--I		0123--6		0173--E		0223--CNT		0273--YTO	
0024--XTO		0074--CNT		0124--CNT		0174--C		0224--XTO		0274--CLR	
0025--E		0075--CNT		0125--FMT		0175--L		0225--IND		0275--CLR	
0026--YTO		0076--a		0126--FMT		0176--I		0226--6		0276--I	
0027--CLR		0077--UP		0127--L		0177--N		0227--CNT		0277--YTO	
0028--YTO		0078--I		0128--A		0178--A		0228--1		0278--XTO	
0029--E		0079--+		0129--XTO		0179--XTO		0229--XTO		0279--CNT	
0030--C		0080--XFR		0130--I		0180--I		0230--+		0280--YTO	
0031--O		0081--O		0131--XTO		0181--O		0231--6		0281--XTO	
0032--H		0082--O		0132--1/X		0182--H		0232--CNT		0282--A	
0033--D		0083--O		0133--D		0183--FMT		0233--CNT		0283--XTO	
0034--YTO		0084--CNT		0134--E		0184--CNT		0234--S/R		0284--I	
0035--CLR		0085--XKY		0135--FMT		0185--CNT		0235--O		0285--O	
0036--CLR		0086--O		0136--CNT		0186--STP		0236--O		0286--H	
0037--GTO		0087--2		0137--CNT		0187--CNT		0237--O		0287--FMT	
0038--CNT		0088--5		0138--STP		0188--CNT		0238--O		0288--CNT	
0039--O		0089--O		0139--CNT		0189--GTO		0239--O		0289--CNT	
0040--F		0090--CNT		0140--CNT		0190--S/R		0240--O		0290--1	
0041--CNT		0091--YTO		0141--GTO		0191--LBL		0241--O		0291--XTO	
0042--YTO		0092--O		0142--S/P		0192--A		0242--O		0292--O	
0043--XTO		0093--CNT		0143--LBL		0193--CNT		0243--O		0293--O	
0044--A		0094--GTO		0144--A		0194--CNT		0244--O		0294--5	
0045--XTO		0095--O		0145--CNT		0195--S/R		0245--O		0295--GTO	
0046--I		0096--O		0146--CNT		0196--CNT		0246--O		0296--S/R	
0047--O		0097--7		0147--FMT		0197--CNT		0247--O		0297--LBL	
0048--H		0098--O		0148--FMT		0198--CNT		0248--O		0298--2	
0049--YTO		0099--CNT		0149--L		0199--CNT		0249--O		0299--CNT	

PROGRAM NAME \_\_\_\_\_ NUMBER \_\_\_\_\_

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STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0300--FMT		0350-- 5		0400--CLR		0450--CNT		0500--FMT		0550-- 0	
0301--FMT		0351--CNT		0401--CNT		0451--CNT		0501--FMT		0551-- 0	
0302-- 2		0352--CNT		0402--FMT		0452--CNT		0502--CLR		0552-- 0	
0303-- N		0353--GTO		0403--FMT		0453--CNT		0503-- 2		0553-- 0	
0304-- D		0354--S/R		0404--CLR		0454--CNT		0504-- N		0554-- 0	
0305--CNT		0355--LBL		0405-- B		0455--CNT		0505-- D		0555-- 0	
0306--YTO		0356-- 2		0406-- A		0456--CNT		0506--CNT		0556-- 0	
0307--XTO		0357--CNT		0407-- L		0457--CNT		0507-- A		0557-- 0	
0308-- R		0358--CNT		0408-- L		0458--CNT		0508-- N		0558-- 0	
0309--XTO		0359--CNT		0409-- 0		0459--CNT		0509-- D		0559-- 0	
0310-- 1		0360--CNT		0410-- 0		0460--FMT		0510--CNT		0560-- 0	
0311-- 0		0361--CNT		0411-- N		0461--FMT		0511-- 3		0561-- 0	
0312-- N		0362--CNT		0412--CNT		0462--CLR		0512-- 0		0562-- 0	
0313--FMT		0363--CNT		0413-- 1		0463-- 1		0513-- D		0563-- 0	
0314--CNT		0364--CNT		0414-- 0		0464--YTO		0514--CLR		0564-- 0	
0315--CNT		0365--CNT		0415--YTO		0465--XTO		0515--CLR		0565-- 0	
0316-- 2		0366--CNT		0416-- .		0466--CNT		0516--FMT		0566-- 0	
0317--XTO		0367--CNT		0417--CLR		0467-- A		0517--CNT		0567-- 0	
0318-- 0		0368--CNT		0418--CLR		0468-- N		0518--CNT		0568-- 0	
0319-- 0		0369--CNT		0419-- 1		0469-- D		0519--CNT		0569-- 0	
0320-- 5		0370--CNT		0420--YTO		0470--CNT		0520-- 2		0570-- 0	
0321--CNT		0371--CNT		0421--XTO		0471-- 3		0521-- UP		0571-- 0	
0322--CNT		0372--CNT		0422--CNT		0472-- 0		0522-- 3		0572-- 0	
0323--GTO		0373--CNT		0423-- A		0473-- D		0523--CNT		0573-- 0	
0324--S/R		0374--CNT		0424-- N		0474--CLR		0524--CNT		0574-- 0	
0325--LBL		0375--CNT		0425-- D		0475--CLR		0525--GTO		0575-- 0	
0326-- 2		0376--CNT		0426--CNT		0476--FMT		0526--S/R		0576-- 0	
0327--CNT		0377--CNT		0427-- 2		0477--CNT		0527--LBL		0577-- 0	
0328--CNT		0378--CNT		0428-- N		0478--CNT		0528-- 4		0578-- 0	
0329--CNT		0379--CNT		0429-- D		0479--CNT		0529--CNT		0579-- 0	
0330--FMT		0380--CNT		0430--CLR		0480--CNT		0530--CNT		0580-- 0	
0331--FMT		0381--CNT		0431--CLR		0481--CNT		0531--CNT		0581-- 0	
0332-- 3		0382--CNT		0432--FMT		0482--CNT		0532--CNT		0582-- 0	
0333-- 0		0383--CNT		0433--CNT		0483--CNT		0533--CNT		0583-- 0	
0334-- D		0384--CNT		0434--CNT		0484--CNT		0534--CNT		0584-- 0	
0335--CNT		0385--CNT		0435--CNT		0485-- 1		0535--CNT		0585-- 0	
0336--YTO		0386--CNT		0436--CNT		0486-- UP		0536--CNT		0586-- 0	
0337--XTO		0387--CNT		0437--CNT		0487-- 3		0537--CNT		0587-- 0	
0338-- A		0388--CNT		0438--CNT		0488--GTO		0538--CNT		0588-- 0	
0339--XTO		0389--CNT		0439-- 1		0489--S/R		0539--CNT		0589-- 0	
0340-- 1		0390--CNT		0440-- UP		0490--LBL		0540--GTO		0590-- 0	
0341-- 0		0391--CNT		0441-- 2		0491-- 4		0541-- 0		0591-- 0	
0342-- N		0392--CNT		0442--CNT		0492--CNT		0542-- 2		0592-- 0	
0343--FMT		0393--CNT		0443--GTO		0493--CNT		0543-- 5		0593-- 0	
0344--CNT		0394--CNT		0444--S/R		0494--CNT		0544-- 0		0594-- 0	
0345--CNT		0395--CNT		0445--LBL		0495--CNT		0545--CNT		0595-- 0	
0346-- 3		0396--CNT		0446-- 4		0496--CNT		0546--CNT		0596-- 0	
0347--XTO		0397--CNT		0447--CNT		0497--CNT		0547--CNT		0597-- 0	
0348-- 0		0398--CNT		0448--CNT		0498--CNT		0548--CNT		0598-- 0	
0349-- 0		0399--CNT		0449--CNT		0499--CNT		0549--CNT		0599-- 0	

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PAGE \_\_\_\_\_ OF \_\_\_\_\_

PROGRAM NAME \_\_\_\_\_ NUMBER \_\_\_\_\_

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0600--LCL		0650--CHS		0700--XFR		0750--CNT		0800--CNT		0850--0	
0601--0		0651--UP		0701--0		0751--CNT		0801--CNT		0851--0	
0602--JTD		0652--0		0702--0		0752--1		0802--DN		0852--0	
0603--JTD		0653--6		0703--0		0753--XTO		0803--+		0853--0	
0604--IND		0654--0		0704--N		0754--+		0804--CNT		0854--0	
0605--0		0655--+		0705--UP		0755--a		0805--CNT		0855--0	
0606--0		0656--DN		0706--CNT		0756--CNT		0806--DN		0856--0	
0607--5		0657--CNT		0707--CNT		0757--CNT		0807--CNT		0857--0	
0608--CNT		0658--CNT		0708--XFR		0758--CNT		0808--CNT		0858--0	
0609--CNT		0659--CNT		0709--0		0759--CNT		0809--CNT		0859--0	
0610--KEY		0660--XTO		0710--0		0760--XFR		0810--XTO		0860--0	
0611--PNT		0661--0		0711--7		0761--0		0811--IND		0861--0	
0612--KEY		0662--0		0712--M		0762--0		0812--a		0862--0	
0613--PNT		0663--7		0713--X		0763--7		0813--CNT		0863--0	
0614--PNT		0664--CNT		0714--CNT		0764--N		0814--CNT		0864--0	
0615--KEY		0665--CNT		0715--CNT		0765--CHS		0815--1		0865--0	
0616--CNT		0666--1		0716--XFR		0766--UP		0816--XTO		0866--0	
0617--UP		0667--XTO		0717--0		0767--CNT		0817--+		0867--0	
0618--5		0668--		0718--0		0768--CNT		0818--a		0868--0	
0619--0		0669--a		0719--6		0769--XFR		0819--CNT		0869--0	
0620--7		0670--XFR		0720--M		0770--0		0820--CNT		0870--0	
0621--		0671--IND		0721--CHS		0771--0		0821--CNT		0871--0	
0622--CNT		0672--a		0722--UP		0772--0		0822--CNT		0872--0	
0623--CNT		0673--CNT		0723--CNT		0773--N		0823--CNT		0873--0	
0624--JTD		0674--CNT		0724--CNT		0774--X		0824--CNT		0874--0	
0625--a		0675--CNT		0725--XFR		0775--CNT		0825--XFR		0875--0	
0626--XFR		0676--XTO		0726--0		0776--CNT		0826--0		0876--0	
0627--IND		0677--0		0727--0		0777--XFR		0827--0		0877--0	
0628--a		0678--0		0728--7		0778--0		0828--6		0878--0	
0629--CNT		0679--6		0729--N		0779--0		0829--N		0879--0	
0630--CNT		0680--XFR		0730--X		0780--6		0830--UP		0880--0	
0631--RUP		0681--0		0731--CNT		0781--M		0831--CNT		0881--0	
0632--+		0682--0		0732--CNT		0782--CHS		0832--CNT		0882--0	
0633--DN		0683--5		0733--XFR		0783--UP		0833--XFR		0883--0	
0634--CNT		0684--CNT		0734--0		0784--CNT		0834--0		0884--0	
0635--XTO		0685--CNT		0735--0		0785--CNT		0835--0		0885--0	
0636--0		0686--UP		0736--0		0786--XFR		0836--0		0886--0	
0637--CNT		0687--1		0737--M		0787--0		0837--M		0887--0	
0638--CNT		0688--		0738--X		0788--0		0838--X		0888--0	
0639--1		0689--0		0739--CNT		0789--7		0839--CNT		0889--0	
0640--XTO		0690--X		0740--CNT		0790--M		0840--CNT		0890--0	
0641--		0691--5		0741--DN		0791--X		0841--DN		0891--0	
0642--		0692--1		0742--+		0792--CNT		0842--CNT		0892--0	
0643--CNT		0693--+		0743--CNT		0793--CNT		0843--CNT		0893--0	
0644--CNT		0694--CNT		0744--CNT		0794--XFR		0844--CNT		0894--0	
0645--CHP		0695--CNT		0745--DN		0795--0		0845--CNT		0895--0	
0646--IND		0696--JTD		0746--CNT		0796--0		0846--XTO		0896--0	
0647--a		0697--a		0747--XTO		0797--0		0847--IND		0897--0	
0648--CNT		0698--CNT		0748--IND		0798--M		0848--a		0898--0	
0649--CNT		0699--CNT		0749--0		0799--X		0849--S/R		0899--0	

PROGRAM NAME \_\_\_\_\_ NUMBER \_\_\_\_\_

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
0900--LBI		0950-- 1		1000--IND		1050--XFR		1100--CNT		1150--CNT	
0901-- 4		0951--XTO		1001-- 0		1051-- 0		1101--CNT		1151--CNT	
0902--CNT		0952-- +		1002--CNT		1052-- 6		1102--XFR		1152-- DN	
0903--CNT		0953-- 0		1003--CNT		1053-- 5		1103-- 0		1153-- -	
0904--CNT		0954--CNT		1004--XTO		1054--CNT		1104-- 6		1154-- DN	
0905--XTO		0955--CNT		1005-- 0		1055--CNT		1105-- 4		1155--CNT	
0906-- 6		0956--XFR		1006-- 6		1056-- UP		1106-- UP		1156--CNT	
0907--CNT		0957--IND		1007-- 0		1057--XFR		1107--XFR		1157--CNT	
0908--CNT		0958-- 0		1008--CNT		1058-- 0		1108-- 0		1158--CNT	
0909-- 1		0959--CNT		1009--CNT		1059-- 6		1109-- 6		1159--XTO	
0910-- -		0960--CNT		1010-- 1		1060-- 9		1110-- 9		1160-- 0	
0911-- 3		0961--XTO		1011--XTO		1061-- X		1111-- X		1161-- 6	
0912-- 0		0962-- 0		1012-- +		1062--CNT		1112--CNT		1162-- 3	
0913-- 5		0963-- 6		1013-- 0		1063--CNT		1113--CNT		1163--CNT	
0914-- 1		0964-- 6		1014--CNT		1064--XFR		1114-- DN		1164--CNT	
0915-- +		0965--CNT		1015--CNT		1065-- 0		1115-- -		1165--CNT	
0916--CNT		0966--CNT		1016--XFR		1066-- 6		1116-- DN		1166--CNT	
0917--CNT		0967-- 6		1017--IND		1067-- 6		1117--CNT		1167--CNT	
0918--YTO		0968-- UP		1018-- 0		1068-- UP		1118--CNT		1168--CNT	
0919-- 0		0969-- 1		1019--CNT		1069--XFR		1119--CNT		1169--CNT	
0920--CNT		0970-- -		1020--CNT		1070-- 0		1120--XTO		1170--CNT	
0921--CNT		0971-- 3		1021--XTO		1071-- 6		1121-- 0		1171--XSO	
0922--XFR		0972-- X		1022-- 0		1072-- 0		1122-- 6		1172-- UP	
0923--IND		0973-- 5		1023-- 6		1073-- X		1123-- 2		1173--CNT	
0924-- 0		0974-- 1		1024-- 9		1074--CNT		1124--CNT		1174--CNT	
0925--CNT		0975-- +		1025--CNT		1075--CNT		1125--CNT		1175--XFR	
0926--CNT		0976--CNT		1026--CNT		1076-- DN		1126--CNT		1176-- 0	
0927--XTO		0977--CNT		1027--CNT		1077-- -		1127--CNT		1177-- 6	
0928-- 0		0978--YTO		1028--CNT		1078-- DN		1128--XFR		1178-- 2	
0929-- 6		0979-- 0		1029--CNT		1079--CNT		1129-- 0		1179--XSO	
0930-- 4		0980--CNT		1030--CNT		1080--CNT		1130-- 6		1180-- +	
0931--CNT		0981--CNT		1031--CNT		1081--CNT		1131-- 4		1181--CNT	
0932--CNT		0982--XFR		1032--CNT		1082--XTO		1132-- UP		1182--CNT	
0933-- 1		0983--IND		1033--CNT		1083-- 0		1133--XFR		1183--XFR	
0934--XTO		0984-- 0		1034--CNT		1084-- 6		1134-- 0		1184-- 0	
0935-- +		0985--CNT		1035--CNT		1085-- 1		1135-- 6		1185-- 6	
0936-- 0		0986--CNT		1036--CNT		1086--CNT		1136-- 0		1186-- 1	
0937--CNT		0987--XTO		1037--CNT		1087--CNT		1137-- X		1187--XSO	
0938--CNT		0988-- 0		1038--CNT		1088--CNT		1138--CNT		1188-- +	
0939--XFR		0989-- 6		1039--CNT		1089--CNT		1139--CNT		1189--CNT	
0940--IND		0990-- 7		1040--CNT		1090--XFR		1140--XFR		1190--CNT	
0941-- 0		0991--CNT		1041--CNT		1091-- 0		1141-- 0		1191-- DN	
0942--CNT		0992--CNT		1042--CNT		1092-- 6		1142-- 6		1192-- 7	
0943--CNT		0993-- 1		1043--CNT		1093-- 6		1143-- 5		1193--CNT	
0944--XTO		0994--XTO		1044--CNT		1094-- UP		1144-- UP		1194--CNT	
0945-- 0		0995-- +		1045--CNT		1095--XFR		1145--XFR		1195--CNT	
0946-- 6		0996-- 0		1046--CNT		1096-- 0		1146-- 0		1196--CNT	
0947-- 5		0997--CNT		1047--CNT		1097-- 6		1147-- 6		1197--XTO	
0948--CNT		0998--CNT		1048--CNT		1098-- 7		1148-- 7		1198-- 0	
0949--CNT		0999--XFR		1049--CNT		1099-- X		1149-- X		1199-- 6	

BEST AVAILABLE COPY

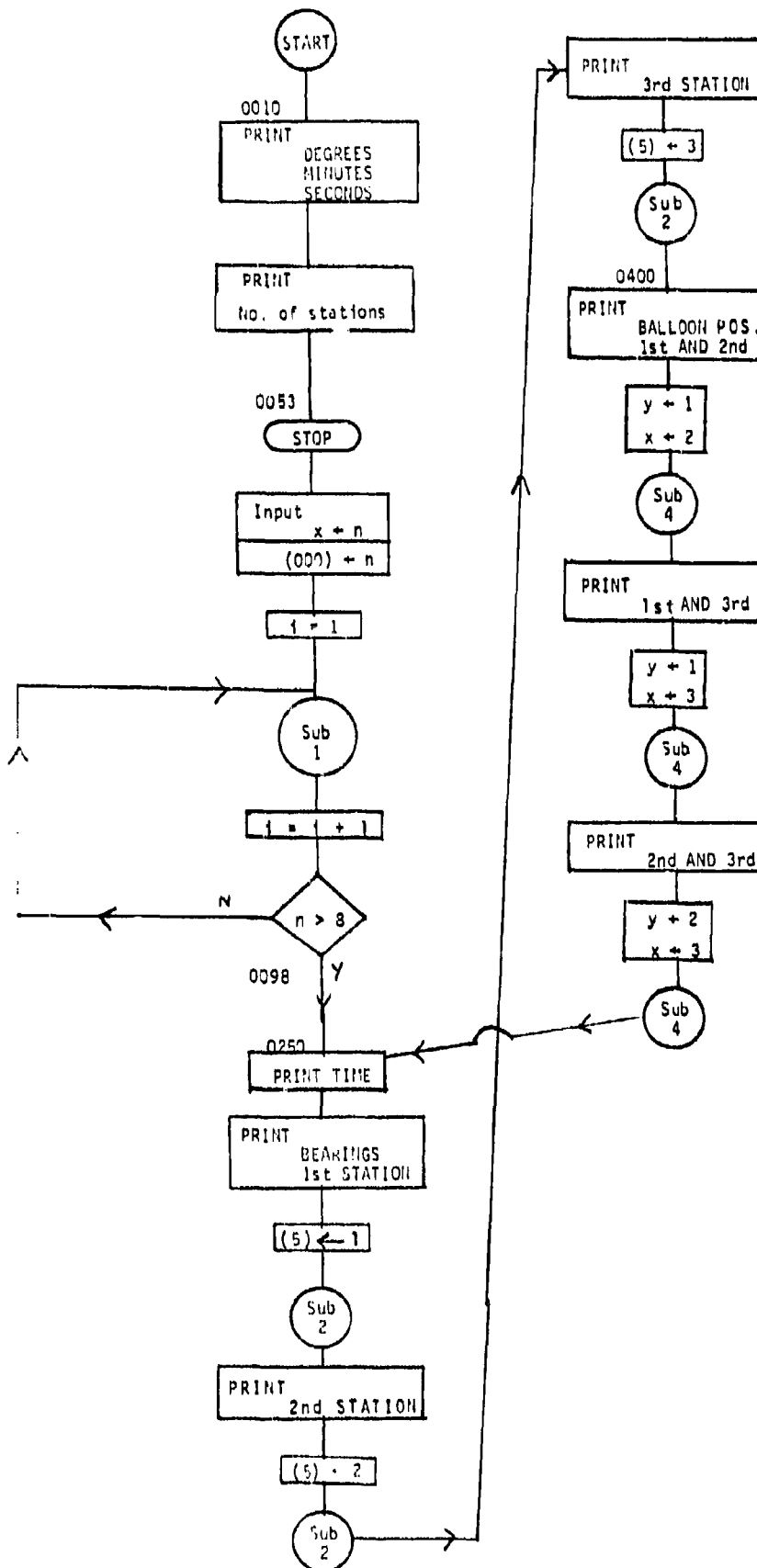
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PAGE \_\_\_\_\_ OF \_\_\_\_\_

PROGRAM NAME \_\_\_\_\_

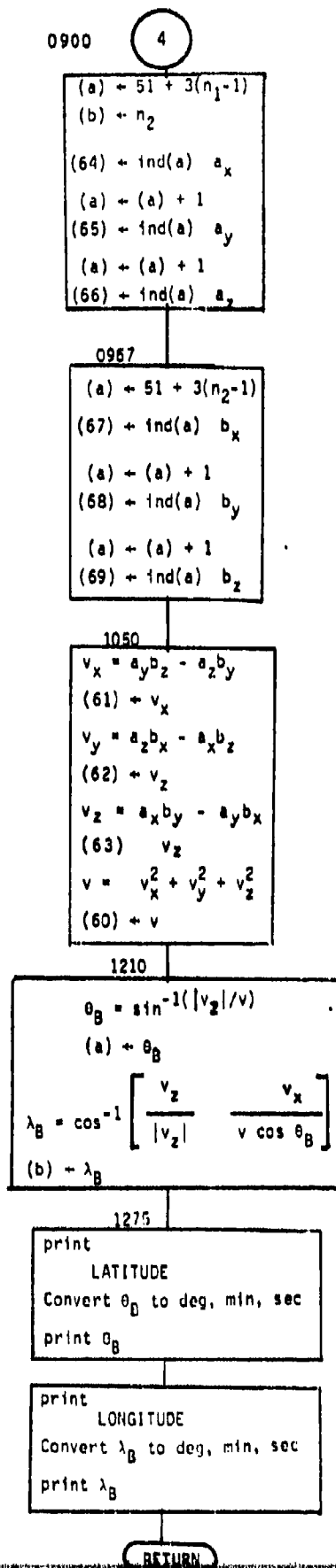
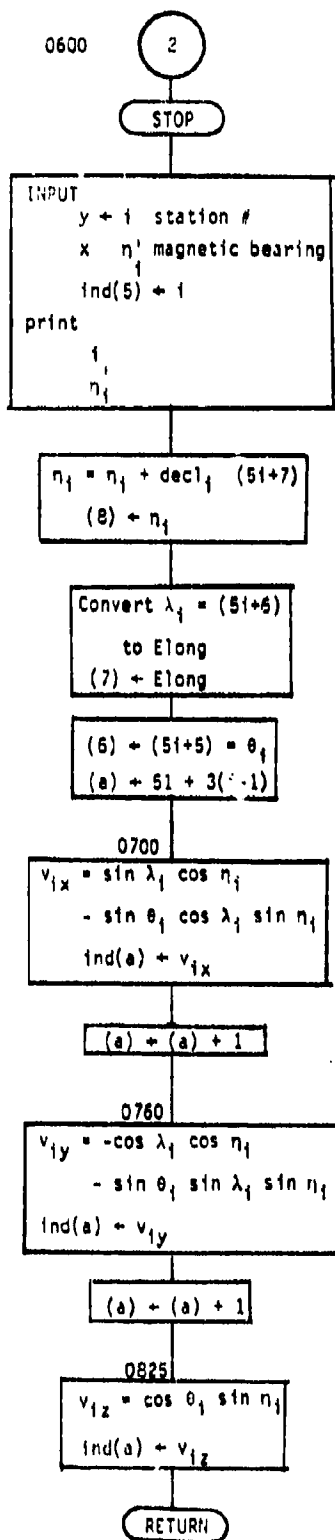
NUMBER \_\_\_\_\_

STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY	STEP	KEY
1200--	A	1250--	H	1300--	CNT						
1201--	DN	1251--	DN	1301--	CNT						
1202--	CNT	1252--	DIV	1302--	CNT						
1203--	CNT	1253--	DN	1303--	CNT						
1204--	CNT	1254--	L	1304--	CNT						
1205--	CNT	1255--	H	1305--	CNT						
1206--	CNT	1256--	CNT	1306--	CNT						
1207--	CNT	1257--	CNT	1307--	CNT						
1208--	CNT	1258--	XTO	1308--	CNT						
1209--	CNT	1259--	b	1309--	CNT						
1210--	UF	1260--	CNT	1310--	FMT						
1211--	XFR	1261--	CNT	1311--	FMT						
1212--	0	1262--	CNT	1312--	L						
1213--	6	1263--	CNT	1313--	0						
1214--	3	1264--	CNT	1314--	N						
1215--	CNT	1265--	CNT	1315--	G						
1216--	UF	1266--	CNT	1316--	I						
1217--	G	1267--	CNT	1317--	XTO						
1218--	KEY	1268--	CNT	1318--	1/X						
1219--	DIV	1269--	CNT	1319--	D						
1220--	RUP	1270--	CNT	1320--	E						
1221--	DIV	1271--	CNT	1321--	FMT						
1222--	DN	1272--	CNT	1322--	CNT						
1223--	L	1273--	CNT	1323--	b						
1224--	H	1274--	CNT	1324--	CNT						
1225--	XTO	1275--	FMT	1325--	CNT						
1226--	0	1276--	FMT	1326--	CNT						
1227--	CNT	1277--	L	1327--	CNT						
1228--	CNT	1278--	R	1328--	CNT						
1229--	CNT	1279--	XTO	1329--	CNT						
1230--	CNT	1280--	I	1330--	CNT						
1231--	CNT	1281--	XTO	1331--	K						
1232--	CNT	1282--	1/X	1332--	7						
1233--	CNT	1283--	D	1333--	CNT						
1234--	CNT	1284--	E	1334--	CNT						
1235--	UF	1285--	FMT	1335--	RUP						
1236--	XFR	1286--	CNT	1336--	PNT						
1237--	0	1287--	CNT	1337--	RUP						
1238--	6	1288--	0	1338--	PNT						
1239--	1	1289--	K	1339--	RUP						
1240--	CNT	1290--	7	1340--	PNT						
1241--	RUP	1291--	CNT	1341--	PNT						
1242--	0	1292--	CNT	1342--	CNT						
1243--	XTO	1293--	RUP	1343--	CNT						
1244--	0	1294--	PNT	1344--	S/E						
1245--	6	1295--	RUP	1345--	CNT						
1246--	0	1296--	PNT	1346--	CNT						
1247--	CNT	1297--	RUP	1347--	CNT						
1248--	RUP	1298--	PNT	1348--	CNT						
1249--	H	1299--	PNT	1349--	END						

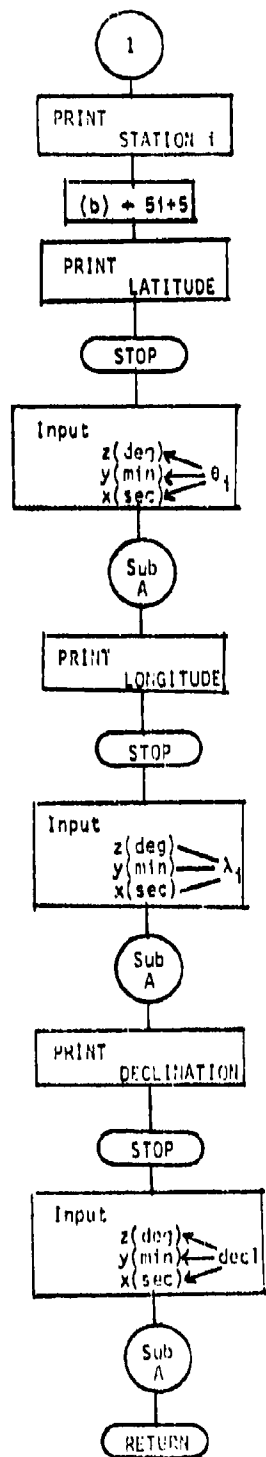


SUBROUTINE  $v_i = OS_i \times S_i B$

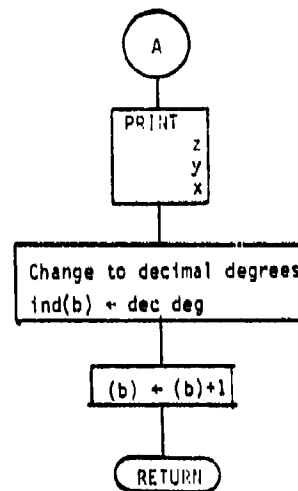
SUBROUTINE  $y=n_1, x=n_2$



SUBROUTINE 1

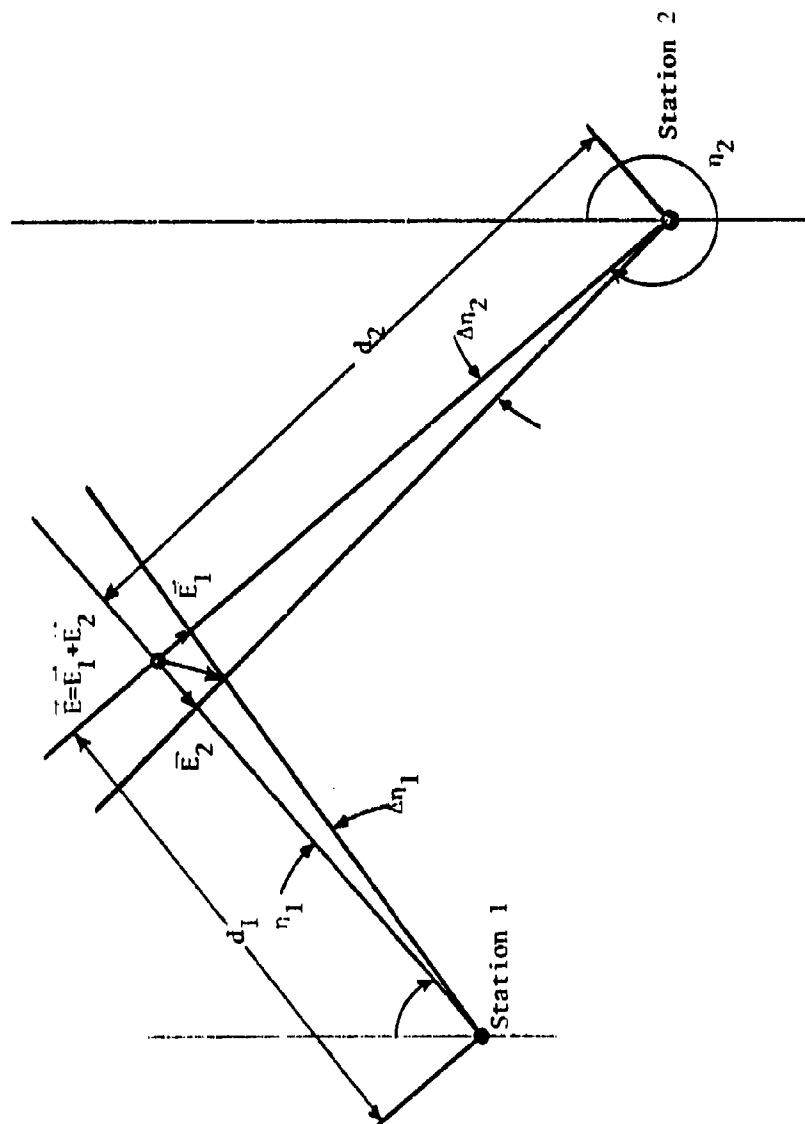


SUBROUTINE A



000 # of stations	035 $\theta_6$	} Station #6
001 # of 1st station	036 $\lambda_6$	
002 # of 2nd station	037 decl <sub>6</sub>	
003 # of 3rd station	038	
004	039	
005 i	040 $\theta_7$	} Station #7
006 $\theta_{n_1}$	041 $\lambda_7$	
007 $\lambda_{n_1}$	042 decl <sub>7</sub>	
008 $n_{n_1}$	043	
009	044	
010 $\theta_1$	045 $\theta_8$	} Station #8
011 $\lambda_1$	046 $\lambda_8$	
012 decl <sub>1</sub>	047 decl <sub>8</sub>	
013	048	
014	049	
015 $\theta_2$	050	
016 $\lambda_2$	051 $v_{1x}$	
017 decl <sub>2</sub>	052 $v_{1y}$	
018	053 $v_{1z}$	
019	054 $v_{2x}$	
020 $\theta_3$	055 $v_{2y}$	
021 $\lambda_3$	056 $v_{2z}$	
022 decl <sub>3</sub>	057 $v_{3x}$	
023	058 $v_{3y}$	
024	059 $v_{3z}$	
025 $\theta_4$	060 $ v $	
026 $\lambda_4$	061 $v_x$	
027 decl <sub>4</sub>	062 $v_y$	
028	063 $v_z$	
029	064 $v_{n1,x}$	
030 $\theta_5$	065 $v_{n1,y}$	
031 $\lambda_5$	066 $v_{n1,z}$	
032 decl <sub>5</sub>	067 $v_{n2,x}$	
033	068 $v_{n2,y}$	
034	069 $v_{n2,z}$	

Registers 71-108  
are not used



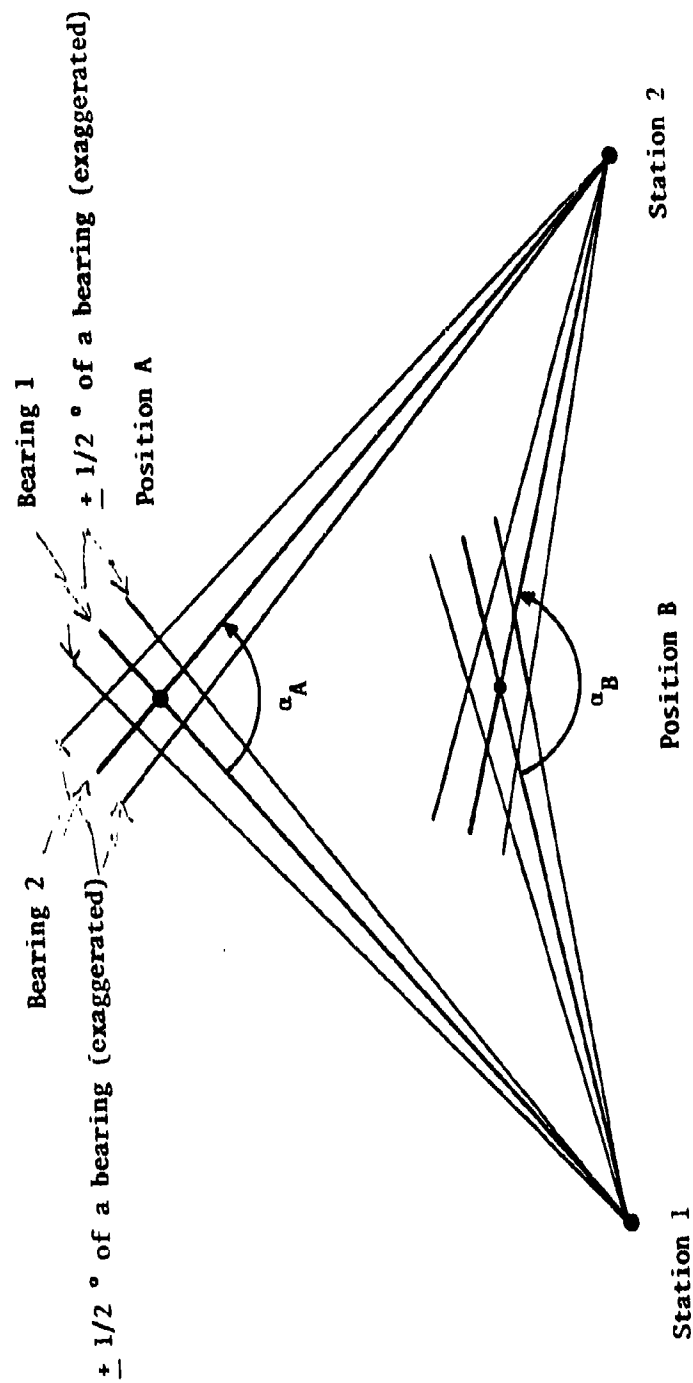


Fig. 9

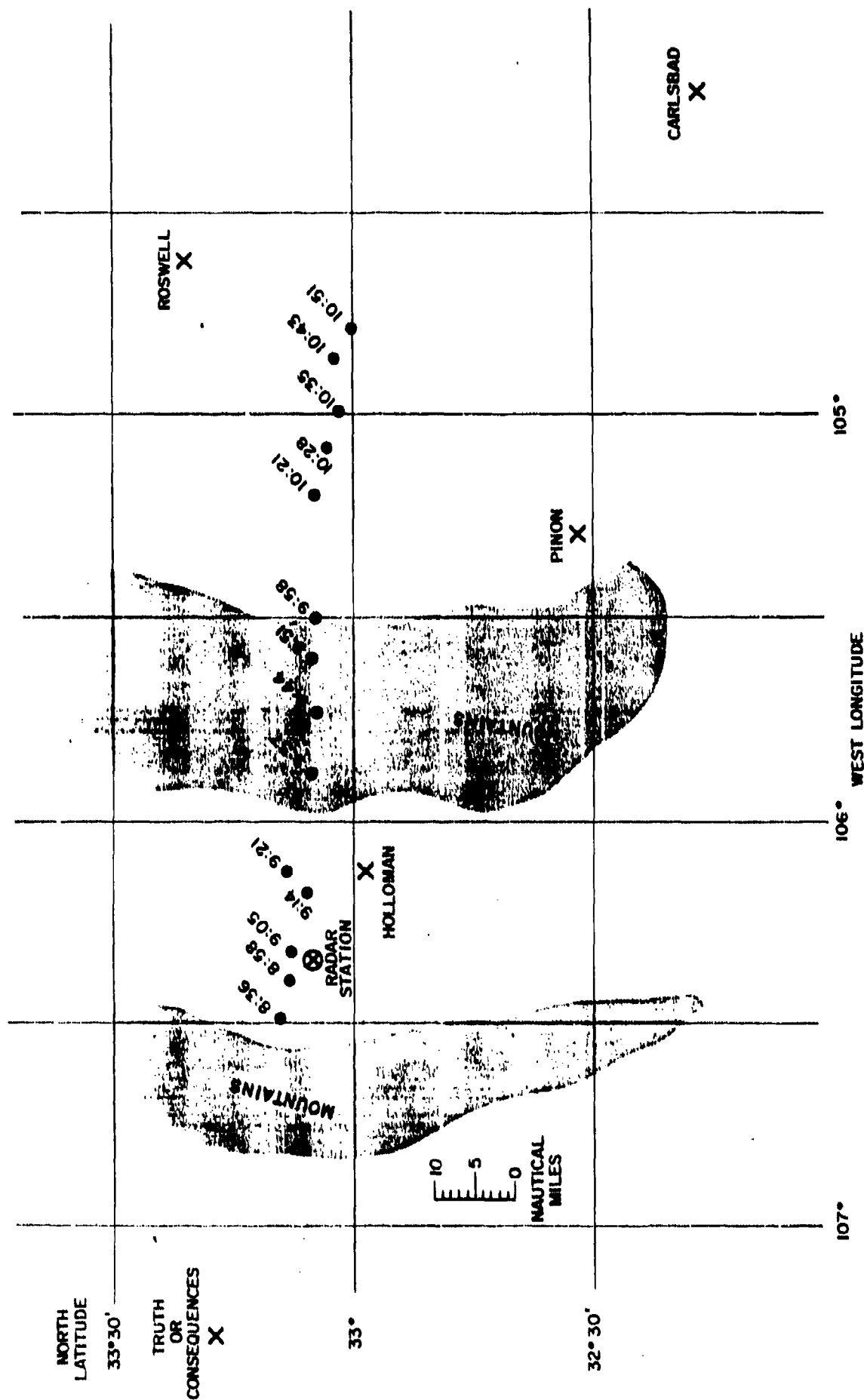


FIG. 10

### III. Tethered-Balloon Experiment

#### Introduction

A series of tests was made in February-March 1975 to aid in the implementation of the 'Tactical Loran Tritether Instrumentation Hook-up'. These tests consisted of flying a 30000 cu ft balloon on tethers of various lengths (100, 500, 1000, and 2000 ft) with various loads (from no load up to 260 lbs) in various winds. The purpose of these tests was to determine the extent of balloon wander under different wind conditions. The balloon position was measured by means of theodolites, and wind azimuth and velocity were measured by instruments attached just under the balloon. Table 1 gives a summary of the different runs made in this series of tests.

#### Analysis

At the beginning the approach was to plot individual data points, with each graph containing data from only one run. Balloon positions with respect to ground zero were plotted with the y-axis representing north and the x-axis east. Values of wind direction and azimuth corresponding to each balloon position were also plotted on these graphs, with the distance from the origin corresponding to the wind velocity and the angle with respect to the y-axis corresponding to the wind azimuth. The two sets

of points were numbered and connected by straight lines, providing a kind of time history of the balloon position, wind direction, and wind speed.

Using the corresponding values of wind azimuth, the balloon positions were then resolved into components parallel and perpendicular to the wind. These values were also plotted as a function of time.

Since not much could be inferred from these types of plots, since the wind data might not have been good enough to justify a point-to-point breakdown, and since it takes a certain amount of time for a given change in wind direction or speed to effect a change in balloon position, it was decided to group together those times when both wind speed and direction were 'approximately constant.' Balloon positions during a given time period were resolved into components parallel and perpendicular to the wind based on the average azimuth of the wind over the whole period. Each time period contains at least five points, and, for some runs in which the wind was nearly constant, it was not necessary to divide the data at all. Balloon positions parallel and perpendicular to the wind were graphed versus time, and each run was graphed separately.

Since this type of time history of balloon wander did not seem to provide any notable insights, data from each of these time periods were grouped together, and statistics

of mean, standard deviation, maximum excursion from ground zero, and spread of excursions about ground zero were calculated. These are statistics of the balloon displacement from ground zero both parallel and perpendicular to the wind. Hence, for each time period of a given run one value for each of the above statistics of balloon displacement was calculated, both parallel and perpendicular to the wind.

In the next set of graphs, each of the statistics of displacement listed above was plotted versus the average wind velocity of the corresponding time interval. Each graph contained the data from all runs of a given tether length, for a given statistical parameter either parallel or perpendicular to the wind. If a particular run was divided into more than one time interval, more than one set of statistics were plotted for that run.

Note that in the case of maximum and minimum excursions, the length of the time interval of the run is important; however, no attempt was made to take this into consideration. On the other hand, in the case of the mean and standard deviation, the length of the time interval is not important as long as it is 'long enough' to provide a representative sample.

From this set of graphs it was seen that in the runs of the 100' tether the balloon wander is a much higher fraction of the cable length than with the other tether lengths.

Note that, in the application for which this will be used, it is the zenith angle of the balloon tether which is important. From this set of graphs it was decided that the 100' tether was not suitable.

One can also see that the 1000' and 2000' tethers are noticeably better than the 500' tether. However, it was felt that performance of these lengths would not justify their use over the 500' tether. Use of a longer cable increases the weight, thereby decreasing the net lift of the balloon, and makes the rigging of the balloon more difficult.

Since it is the zenith angle of the balloon tether which is important in this application, the statistics of balloon displacement listed above were converted to percentage displacement ( $= \text{displacement} / \text{cable length} \times 100$ ). Each statistic was plotted separately versus average wind velocity. For a given statistic, the data for the 500', 1000', and 2000' tethers parallel or perpendicular to the wind were plotted on the same graph.

For mean displacement parallel to the wind, the percentage displacement increases with wind velocity in a way which is almost linear. There is no noticeable dependence on tether length apart from the fact that the 500' tether does not perform quite as well as the two longer tethers. There is a fair amount of scatter in the graph, but the slope of that line which produces the best fit is 1.7% of cable length per

mph of average wind velocity. Therefore, the degree to which the balloon is blown back into the wind is proportional to the average wind velocity.

Mean displacement perpendicular to the wind showed no systematic variation with wind velocity. This is reasonable since the balloon should not have a preferred average position perpendicular to the wind.

Standard deviation parallel and perpendicular to the wind is very variable and, with the exception of winds below 5 mph, shows no variation with wind velocity. Furthermore, the 500' tether data have noticeably higher standard deviations than do the 1000'- or 2000'- tether data. Note that even in high winds, greater than 20 mph, the standard deviation did not increase.

The maximum excursion from ground zero parallel to the wind showed an almost linear increase with wind velocity, but with considerable spread. Again the 500' tether shows, in general, greater displacements than do the two longer tether lengths.

The spread of excursions parallel to the wind shows no relation to wind velocity above 5 mph. But, here again, the 500' tether shows greater displacements.

The variation of these two statistics perpendicular to the wind also showed no variation with wind velocity above 5 mph, but the 500' tether showed significantly greater

displacements than did the two longer tether lengths.

We have seen that parallel to the wind the mean and maximum excursion varied with wind velocity in an almost linear fashion. Dividing each of these statistics by wind velocity, (producing a mean or maximum displacement /mph average wind velocity), these data were plotted versus load to try to find what effect, if any, the load might have on balloon wander. Qualitatively, we know that an increase in the load will increase the angle of attack of the balloon. Up to a certain point this is desirable since it produces an increase in aerodynamic lift, but after this point the aerodynamic lift decreases with angle of attack.

For the "mean displacement parallel to the wind/mph average wind velocity", there seemed to be some correlation with load, i.e., angle of attack. The spread is very large, but one can conclude that the slope of the percentage mean displacement parallel to the wind versus wind velocity is higher when the load is greater.

The slopes computed using the percentage-maximum-excursion statistics show, on the other hand, no correlation with load.

#### Summary

- 1) Data were first resolved into components parallel and perpendicular to the wind.

2) Data were then grouped together into time periods when both the speed and azimuth of the wind were constant.

3) Data for each time period during which the wind was constant were then grouped together to form statistics of the displacement of the balloon with respect to ground zero both parallel and perpendicular to the wind.

4) The percentage displacement of the 100' tether was too high to be suitable for this application. The percentage displacements for the 1000' and 2000' tethers were noticeably smaller than those of the 500', but their performance was not that much better to justify their use over the shorter 500' tether.

5) Percentage mean displacement parallel to the wind varied linearly with wind velocity, with a slope of 1.7%/mph, the balloon being blown back into the wind more and more as the wind increased. Perpendicular to the wind the mean displacement showed no variation with wind velocity, i.e., the balloon had no preferred position perpendicular to the wind.

6) Maximum excursion parallel to the wind varies linearly with wind velocity. This is due to a great extent, however, to the variation of the mean. Perpendicular to the wind there is no systematic variation.

7) Standard deviation parallel and perpendicular to the wind showed no variation with the wind above 5 mph.

8) In the case of the standard deviation parallel and perpendicular to the wind and of the maximum excursion parallel to the wind, the 500' tether showed greater percentage displacements, in general, than did the two longer tethers.

9) Load, in general, seems to produce greater displacements parallel to the wind.

Table 1

	NO LOAD	LOAD BAR ONLY	LOAD BAR +140 LBS BALLAST	LOAD BAR +265 LBS BALLAST
2000' tether	2/26 #4	3/7 #2*	2/27 #8	3/7 #1
	2/27 #4	3/7 #3	2/28 #4	
	3/4 #4*		3/6 #4	
1000' tether	2/26 #3	3/7 #4*	2/27 #7	3/3 #3
	2/27 #3		2/28 #3	
	3/4 #3		3/6 #3	
500' tether	2/26 #2	2/26 #5	2/27 #6	3/3 #2*
	2/27 #2	3/3 #5	2/28 #2	3/7 #6
	3/4 #2		3/6 #2	
100' tether	2/26 #1	3/3 #4	2/27 #5	3/3 #1*
	2/27 #1		2/28 #1	3/7 #5
	3/4 #1		3/4 #5	
			3/6 #1	

\* NO WIND DATA

#### IV Balloon-Flight Simulation

The following balloon-flight simulations were done.

##### A. Eglin AFB simulation

Using 10 years of wind data from Eglin AFB, balloon positions and statistics of balloon positions were calculated assuming an ascent to 10 mb at a constant ascent rate of 800 ft/min, letting the balloon float for 0, 1, 4, 6, 8, and 10 hours at 10 mb. This was done using wind data for days 1-10, 11-20, and 21-31 in each of the months from April to September.

The wind data were received on a 9-track, phase-encoded tape which had to be converted to a 7-track tape in order to make it compatible with the CDC 6600 at AFGL. Before writing the 7-track, 800-bpi tape the data were sorted by month and day.

The balloon positions and associated statistics were done by a program called CHICSIM, which was modified for this particular job.

##### B. Holloman and White Sands simulation

Using 10 years of wind data from Holloman and White Sands, balloon positions and statistics of balloon positions were calculated assuming ascents to 80, 90, and 100 kft, at a constant ascent rate of 800 ft/min, letting the balloon float for 0, 2, 4, 6, 8, 10, and 12 hours at each of those altitudes.

Each of the above cases was run for days 1-15 and 16-31 for all months of the calendar year.

These wind data were already on a CDC 7-track tape. The data were processed by a program called SIMBALL, which was modified slightly for this particular job.